$ 70.00

MACHINE DESIGN

THE ONLY MAGAZINE OF APPLIED TECHNOLOGY FOR DESIGN ENGINEERING

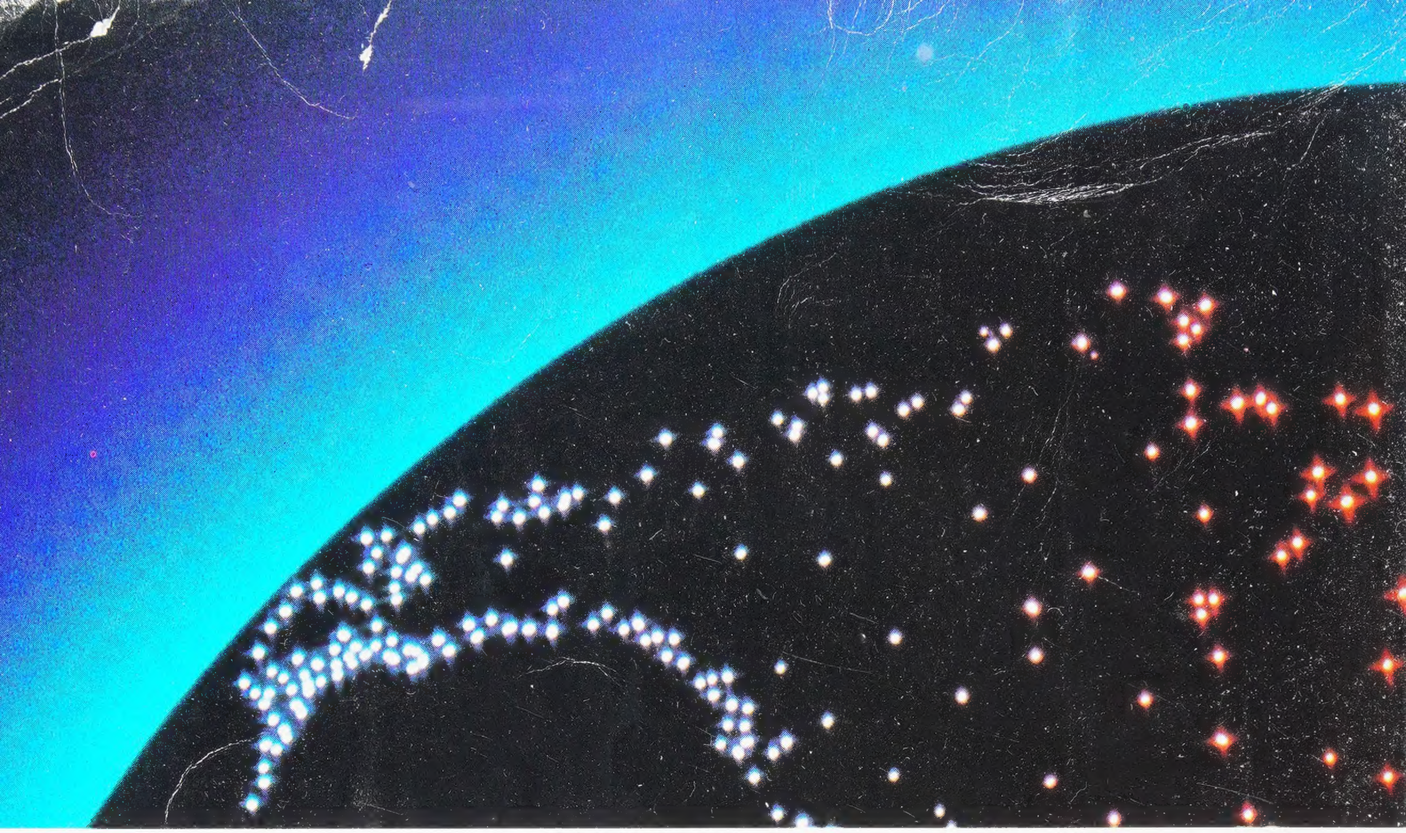
A PENTON PUBLICATION

JUNE 1992

BASICS OF DESIGN ENGINEERING

- ☐ Mechanical Drives
- ☐ Fastening & Joining
- ☐ Electrical/Electronic
- ☐ Fluid Power
- ☐ CAD/CAM
- ☐ Materials

1992

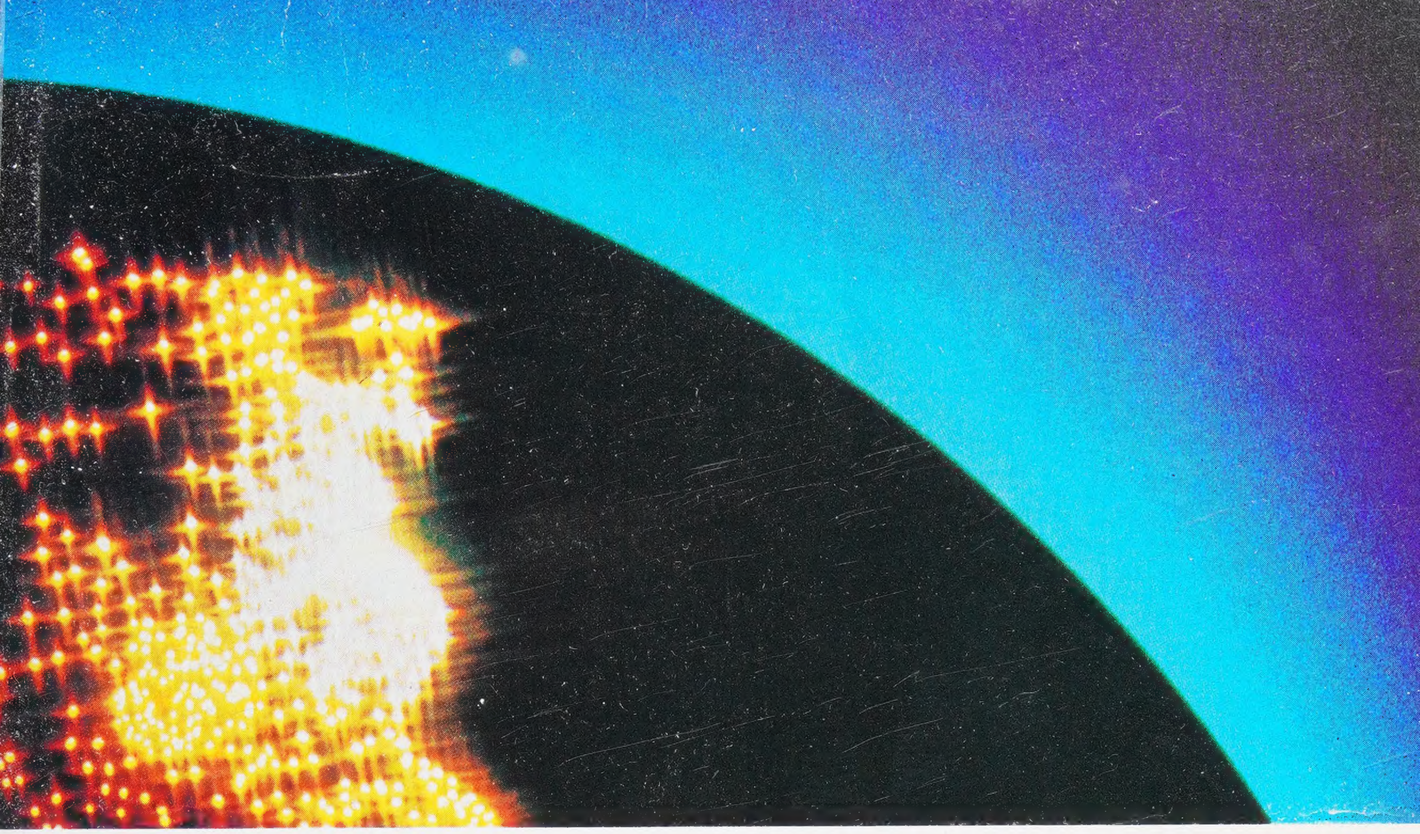


IMO. WORLD

No matter which technology you use—mechanical, electrical, electronic, or fluid power—there's an IMO division with a component that can help your system deliver the performance you need.

IMO

Imo Industries Inc.
3450 Princeton Pike
P.O. Box 6550
Lawrenceville, NJ 08648
609-890-5609
FAX: 609-890-5619



CLASS PERFORMANCE

Adel Fasteners
Blocks, clamps and line supports for aerospace, defense and industrial applications
304-522-7345
Circle 79

Barksdale Controls
Pressure & temperature switches, pressure transducers and valves
213-589-6181
Circle 80

Boston Gear
Speed reducers, precision & stock gears, and adjustable speed/ programmable controls
617-328-3300
Circle 81

CEC Instruments
Pressure & vibration transducers
714-599-3200
Circle 82

Fincor Electronics
AC & DC adjustable speed drives and systems
717-751-4200
Circle 83

Gems Sensors
Point and continuous liquid level sensors, flow sensors, fiber optic level detection and solid state relays
203-747-3000
Circle 678

Heim Bearings
Rolling-element & plain bearings
203-255-1511
Circle 73

IMO Pump
High-performance rotary, positive displacement pumps
704-289-6511
Circle 74

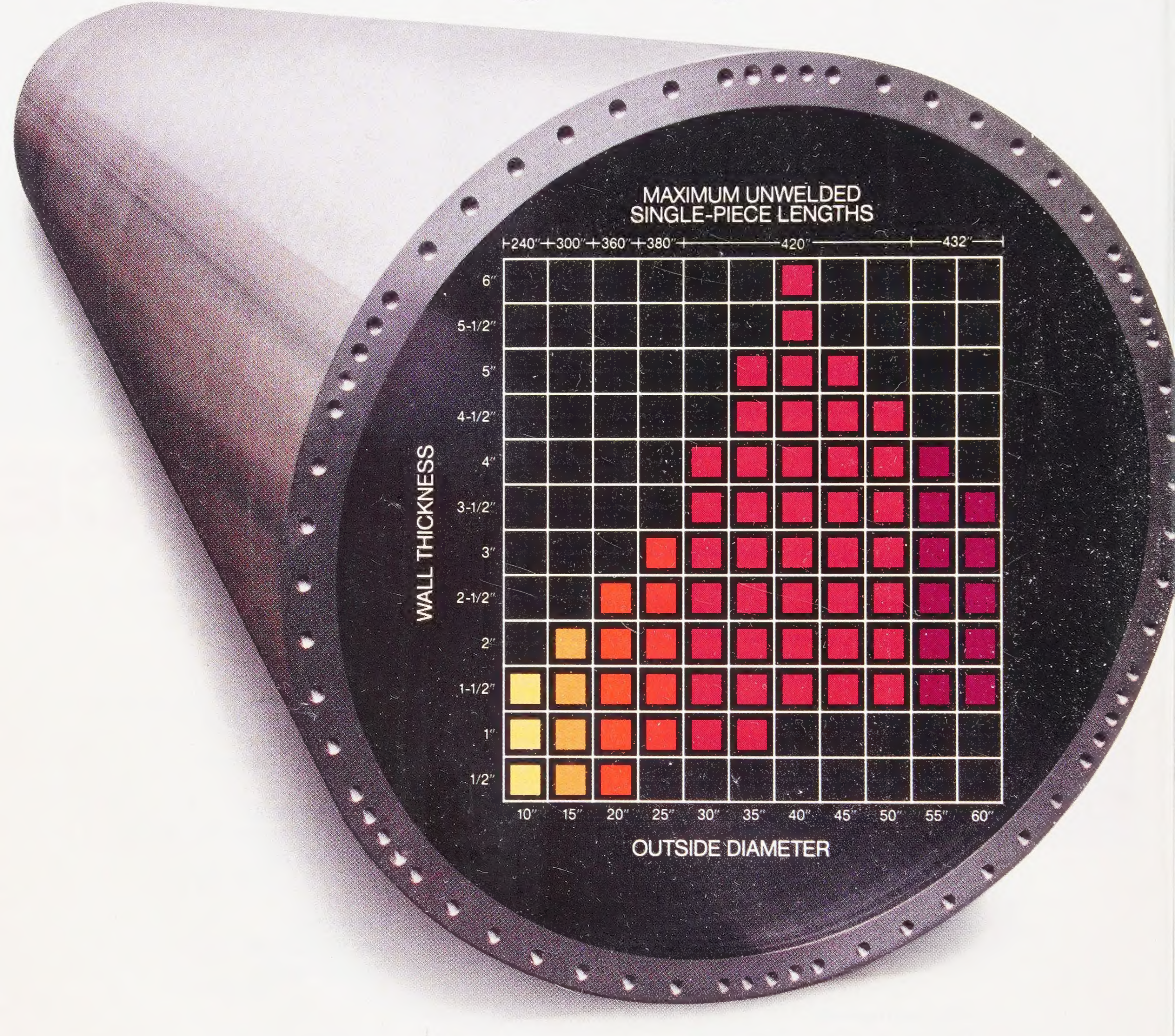
Morse Controls
Red-Jaket® cables and controls
216-653-7702
Circle 75

Turboflex
Dry flexible disk couplings
713-473-6208
Circle 76

Wiggins Connectors
Tube connectors, quick disconnect couplings, composite tubing and assemblies
213-269-9181
Circle 77

Warren Pumps
Centrifugal & rotary screw pumps
413-436-7711
Circle 78

The long and short of large cylinders.



	240"	300"	360"	380"	420"	420"	420"	420"	420"	432"	432"
Wall thickness / O.D.	10"	15"	20"	25"	30"	35"	40"	45"	50"	55"	60"
6"							■				
5-1/2"							■				
5"						■	■	■			
4-1/2"						■	■	■	■		
4"					■	■	■	■	■	■	
3-1/2"					■	■	■	■	■	■	■
3"				■	■	■	■	■	■	■	■
2-1/2"			■	■	■	■	■	■	■	■	■
2"		■	■	■	■	■	■	■	■	■	■
1-1/2"	■	■	■	■	■	■	■	■	■	■	■
1"	■	■	■	■	■	■					
1/2"	■	■	■								

When you need a long, large cylinder, it's good to know that Sandusky can custom produce single-piece unwelded lengths (up to 432"), with large O.D.s (10" to 60"), and heavy wall thicknesses (up to 6") – in a wide variety of materials.

Because our cylinders are centrifugally cast, they provide you with inherent roundness, superior straightness and nondirectional mechanical properties. Our skilled craftsmen can centrifugally cast and machine a wide range of ferrous, copper and nickel-base alloys to meet your corrosion, thermal and mechanical needs.

They draw on decades of centrifugal casting and precision machining experience, working with custom, state-of-the-art manufacturing machinery that ranges from AOD technology to uniquely large lathes.

In short, Sandusky's long, large cylinder capability is one you won't find anywhere else.

For more information about Sandusky's long, large cylinders, call 419-626-5340, Ext. 264, Fax 419-626-8674 or write Sandusky International, Box 5012, Sandusky, OH 44871-8012. Ask for Bulletin #978.

That's the long and short of it.

SANDUSKY INTERNATIONAL®

Turning demanding specs into quality cylinders

MACHINE DESIGN

THE ONLY MAGAZINE OF APPLIED TECHNOLOGY FOR DESIGN ENGINEERING

Volume 64, Number 12

1992 BASICS OF DESIGN ENGINEERING REFERENCE VOLUME

Basics of motion control 7
Mechanical systems 89
Fastening and joining technology 309
Electrical and electronic systems 406
Fluid-power systems 615
CAD/CAM application guide 764
Material selection 833
Advertising index 982
Business staff 984

MACHINE DESIGN *the only magazine of applied technology for design engineering*

mechanical design
electrical design
electronics

fluid power
materials science
structures & stress analysis

manufacturing & assembly
CAD/CAM
R&D

EDITOR
Ronald Khol

EXECUTIVE EDITOR
Leland E. Teschler

SENIOR EDITORS
Lawrence A. Berardinis
James Braham
Kenneth J. Korane

STAFF EDITORS
AUTOMOTIVE
Jennifer K. Chalsma

CAD/CAM
Paul Dvorak

ELECTRICAL/ELECTRONICS
Lawrence A. Berardinis
John R. Gyorki

FLUID POWER
Kenneth J. Korane

MANAGEMENT
James Braham

MANUFACTURING/ASSEMBLY
Stephanie J. Muraski

MATERIALS
Michelle A. Dibble

MECHANICAL
Stephanie J. Muraski

NEWS/FEATURE
Michelle A. Dibble
Stephen J. Mraz
Melissa S. Kennedy

PRODUCTS/LITERATURE
Evelyn Sherman

EDITORIAL
PRODUCTION MANAGER
Denise Greco

EDITORIAL SUPPORT
Liz McAdam
Barbara LoSchiavo
Gayle Wesolek

CONTRIBUTING EDITORS
Ben H. Carlisle
Susan Gibson
James McAlister

ART EDITORS
Randall L. Rubenking
Tony Kovac

LINE ART DIRECTOR
David H. Bosak

CORRESPONDENT
William L. Morse
(Great Britain)

PRESIDENT, DESIGN & ENGINEERING GROUP
James W. Zaremba

VICE PRESIDENT EDITORIAL
Perry Pascarella

PUBLISHER
Joseph M. DiFranco

MACHINE DESIGN, 1100 Superior Ave., Cleveland, OH 44114-2543; 216-696-7000; fax: 216-621-8469

Printed U.S.A., Copyright© 1992. Penton Publishing Inc. All rights reserved.

MACHINE DESIGN (ISSN 0024-9114) is published by Penton Publishing Inc., subsidiary of Pittway Corporation, 1100 Superior Ave., Cleveland, OH 44114-2543. Regular issues are published twice monthly, except for a single issue in December. In addition, a reference volume is published in June and a Product Locator in November. These issues are sold separately and are not included in the regular subscription rates. Subscriptions within the U.S. and its possessions for copies not qualified for controlled circulation: one year, $100; two years, $160. Single copies: regular issues, $9; reference volume, $70; Product Locator, $25.

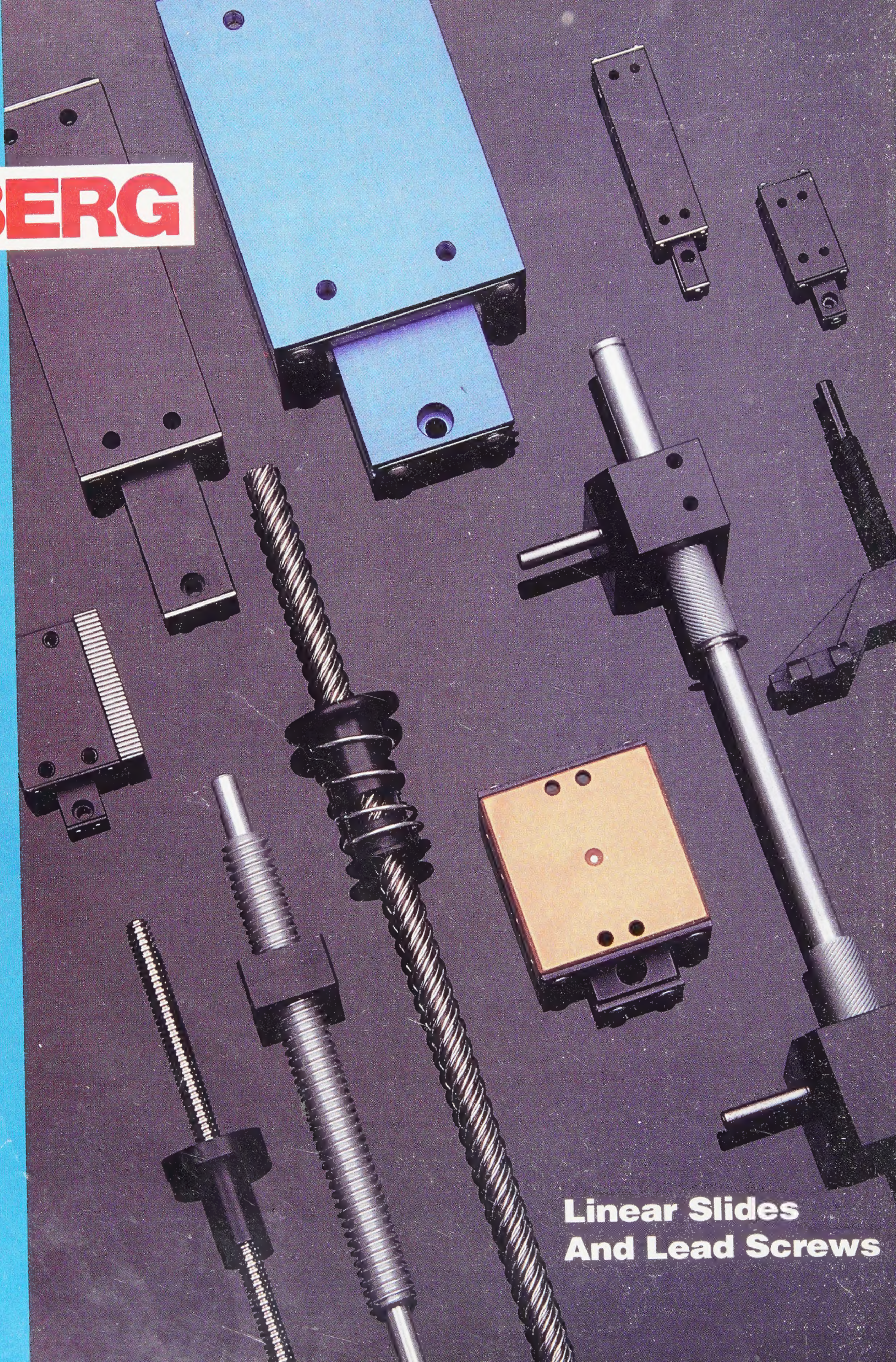
Subscriptions, Canada: one year, $140; two years, $250. Single copies: regular issues, $12; reference volume, $80; Product Locator, $35. Subscriptions, all other countries: one year, $160; two years, $295. Single copies: regular issues, $15; reference volume, $90; Product Locator, $45.

Editorial content is indexed in the Applied Science Technology Index and the Engineering Index, both available in libraries. Microfilm copies available from University Microfilms, Ann Arbor, MI 48103. Fax number (313)665-5022.

Permission to photocopy is granted for users registered with the Copyright Clearance Center (CCC) Inc. to photocopy any article, with the exception of those for which separate copyright ownership is indicated on the first page of the article, provided that the base fee of $1.00 per copy of the article, plus $.50 per page is paid to CCC, 27 Congress St., Salem, MA 01970. (Code No. 0024-9114/91 $1.00 + .50).

Second class postage paid at Cleveland, OH, and additional mailing offices. POSTMASTER: Send change of address notice to MACHINE DESIGN, 1100 Superior Ave., Cleveland, OH 44114-2543; allow six weeks for processing. Can. GST #R126431964.

BERG



Linear Slides And Lead Screws

Berg Precision Mechanical Components

Ball Slides and Roller Slides . . . Helitronics, Inc., a division of W.M. Berg, Inc., manufactures a complete line of off-the-shelf linear ball slides and linear crossed roller slide bearings. Made to the highest quality standards, each component must pass strict inspection requirements at each stage of manufacturing. These quality control steps ensure precise, uniform linear movement with low friction and minimum sideplay.

Available in inch and metric sizes, and in travel lengths ranging from 1/2 inch to 24 inches (13mm to 610mm), parts have flat, parallel, and smooth mounting surfaces. Equipped with mounting holes, they are shipped ready to install with no requirement for modifications or adjustments.

. . . Lead Screws . . . Helitronics, Inc., is a pioneer in the development of high helix angle lead screws. Providing cost-effective solutions to linear actuation problems, the high lead thread form maximizes linear motion and minimizes shaft rotation. The close-tolerance, free-running fit of the nuts is individually matched to their lead screws, making high helix angle lead screws ideal for miniature applications requiring rotary-to-linear or linear-to-rotary actuation.

For applications requiring precision positioning, Helitronics, Inc., also manufactures a newly patented anti-backlash nut. This device, consisting of only three components, utilizes the constant force of a compression spring to push the two nut halves apart, thereby eliminating any play (backlash) that exists between the internal thread of the nut and the external screw thread. To ensure accuracy and repeatability, the nut can be fine-tuned, through the use of the many available spring constants, to meet any preload design requirements.

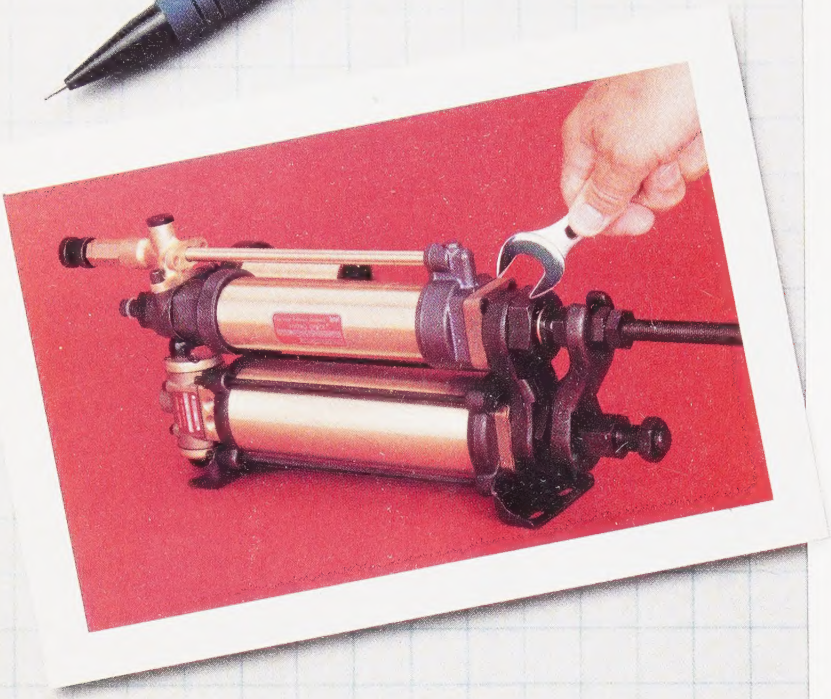
. . . and Over 58,000 Precision Mechanical Components from Stock Due to its extensive manufacturing and engineering capabilities, W.M. Berg is able to make specials to meet any drawing requirements.

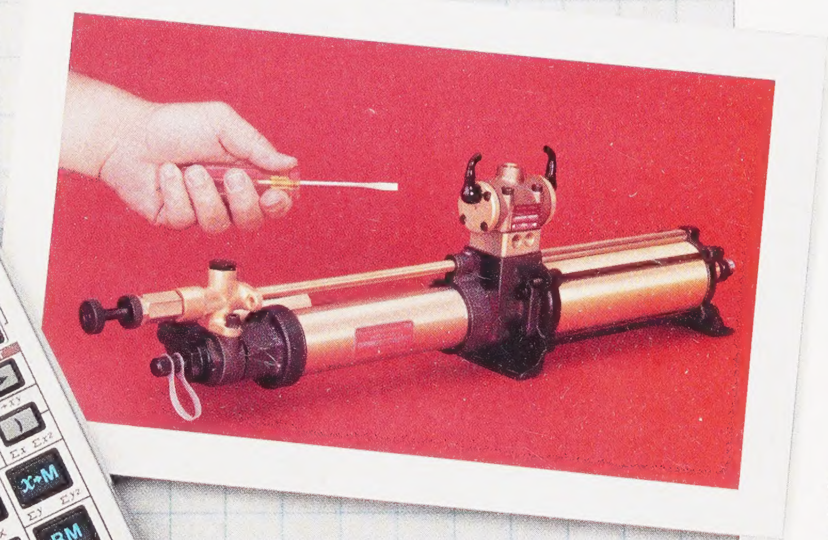
Send for a Free 500-Page Inch (B8) or Metric (M90) Catalog!

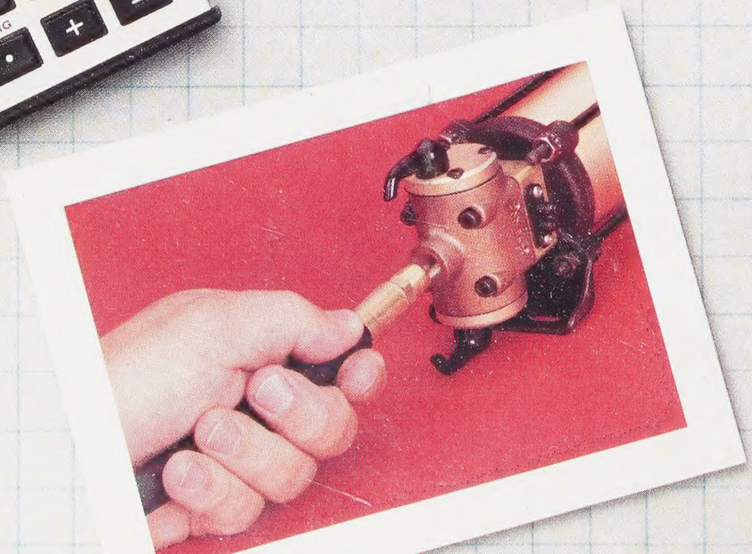
BERG
Precision Mechanical Components
B8
BERG
Precision Mechanical Components
M-90

W. M. Berg, Inc., 499 Ocean Avenue, East Rockaway, NY 11518
Phone: (516) 596-1700 Fax: (516) 599-3274 Telex: 9103506176

Circle 85







Air Motor and Hydro-Check®

A smooth, fast, cost effective linear control system.

Profile: Designed to provide accurate, controlled linear motion for unlimited production applications.

The Bellows Air Motor/Hydro-Check assembly features a double-acting air cylinder with an integral quick response directional control valve coupled to a self-contained hydraulic resistance unit. Designed to provide smooth, controlled feed rates that are not possible to obtain with a conventional pneumatic system. The Hydro-Check also provides a means to "stop," "speed up," or "slow down" the Air Motor at any point in its travel.

There are seven mounting styles, five bore sizes and valve options to satisfy your most stringent needs.

***Pressure:** Up to 175 psi (varies by valve type)*

***Temperature:** -30°F to 180°F (varies by valve type)*

***Bore Sizes:** 1¼," 1¾," 2½," 3⅝"*

***Piston Rods:** ⅝," ¾"*

***Rod Thread:** Full size*

***Head and Caps:** High-strength forgings*

***Piston Seals:** Self-Adjusting Buna N Cup Seals*

For a free catalog, check the Yellow Pages and call your nearby Schrader Bellows distributor.

Or contact Schrader Bellows, 500 S. Wolf Road, Des Plaines, Illinois 60016.

(708) 298-2400

Schrader Bellows®

® Registered Trademark, Schrader Bellows

86-159

Circle 86

MOTION CONTROL

Advertisers

Anaheim Automation 48
Autodesk, Inc. 72-73
Bayside Controls, Inc. 17
Berg, Winfred M., Inc. 4-5,76-77
Dodge/Reliance Electric 19-21
Elmo Motion Control Inc. 87
Eriez Magnetics 8
Industrial Drives,
  A Kollmorgen Div. 11-15
Industrial Indexing Systems, Inc. 68-69
Ormec 79-86
Parker Hannifin Corporation,
  Compumotor Division 33-46
Parker Hannifin Corporation,
  Daedal Division 33-46
Parker Hannifin Corporation,
  Fluid Power Group 23-26
Precision MicroControl Corporation 48
Siemens Industrial Automation 29-31
Superior Electric Co., The 70-71
Thomson Industries, Inc. 49-53,65
Warner Electric/Dana Corp. . . . 57-63,66-67
Zero-Max/Helland
  Research Engineering 48

A
Adaptive control 32
B
Backlash instability 32
Board-level control 56
Boards, dedicated 64
C
Cell controllers 74
Controllers 10
Counters and timers 78
D
Dedicated boards 64
Digital signal processors 54
Dynamic stiffness 47
F
Filtering 28
H
Hydraulic, closed-loop . . . .
I
ICs, special 54
Incremental control 18
Instability, backlash 32
L
Loop variations 28
M
Microcontrollers 54
P
Pneumatic controls 78
Point-to-point control 16
Positioning components 27
Programmable controllers 75
S
Scan time 75
Sequencing 9
Servocontrol 10
Single-board computers 56
Special ICs 55
Speed control 10
T
Timers and counters 78
Types of motion control 9

Basics of motion control

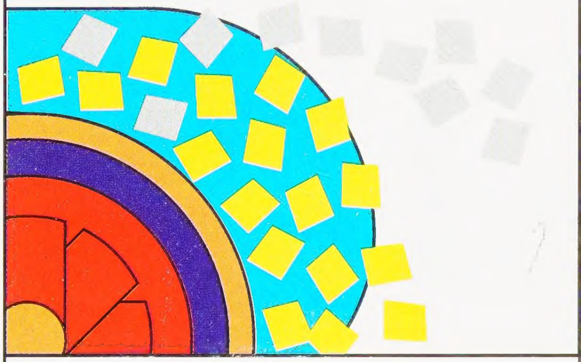
Motion controllers

Only Eriez Can Solve All These Problems.

Problem: Separate non-ferrous metallics from non-metallics.

Solution: Eddy Current Separators

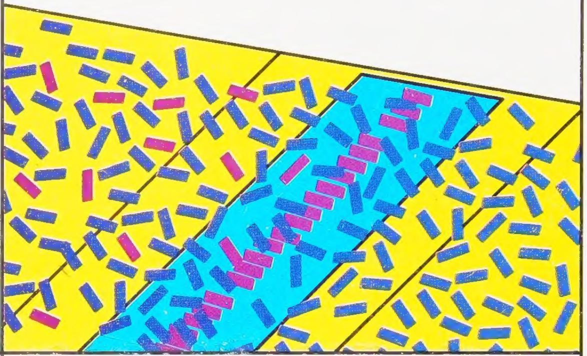
Call: 1-800-345-4946 Info 660



Problem: Iron contaminants in material flow along feed tables or in chutes.

Solution: Plate Magnets

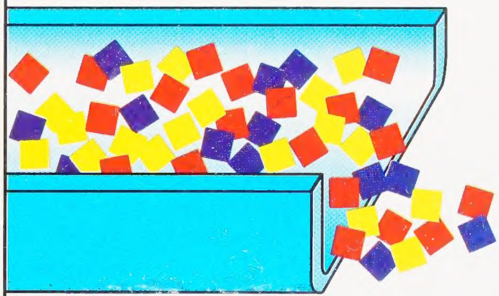
Call: 1-800-345-4946 Info 663



Problem: Bulk materials to be moved dependably.

Solution: Vibratory Feeders

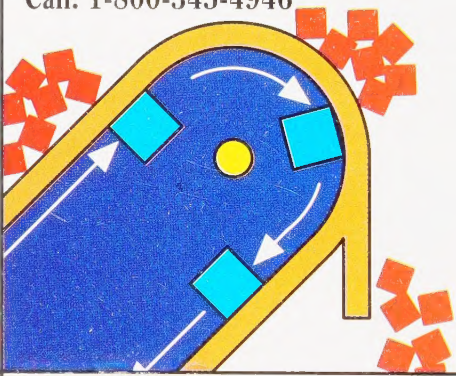
Call: 1-800-345-4946 Info 661



Problem: Steel parts, chips, or stampings to be moved or conveyed.

Solution: Magnetic Chip and Parts Conveyors

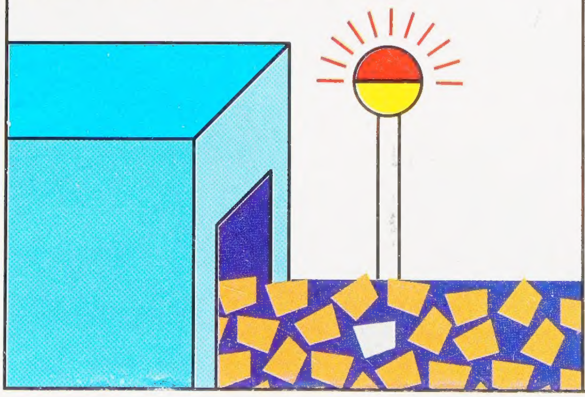
Call: 1-800-345-4946 Info 664



Problem: Metal contaminants in the product stream.

Solution: Metal Detectors

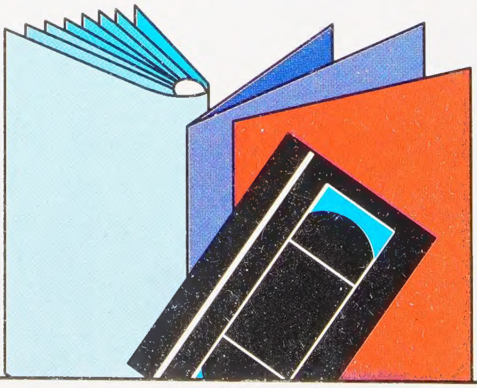
Call: 1-800-345-4946 Info 662



Problem: Question about the technology or capability of Eriez equipment and services.

Solution: Video Kit

Call: 1-800-345-4946 Info 665



World Authority
in Advanced
Technology for
Magnetic, Vibratory,
and Metal Detection
Applications

ERIEZ
MAGNETICS

50
ERIEZ
1942-1992

Eriez Magnetics, Asbury Road at Airport, P.O. Box 10608, Erie, Pennsylvania 16514-0608 USA 814/833-9881 FAX: 814/838-4960
Affiliates: Australia • Brazil • Canada • Japan • Mexico • South Africa • United Kingdom

Basics of motion control

Definitions of motion control vary widely in industry today. Depending on the application, motion control can refer to simple on-off control or a sequencing of events, controlling the speed of a motor, moving objects from one point to another, or precisely constraining the speed, acceleration, and position of a system throughout a move.

Engineers working for the first time in some aspect of motion control may be confused by varying interpretations used in the field. Motion control means different things to different sections of industry. As an introduction, this chapter differentiates among motion-control techniques. It puts each technique into perspective in terms of where typical applications arise.

In many cases, motion-control techniques are intimately tied to the controller as well as to the positioning hardware and actuator. No overview of motion control would be complete without a discussion of the various control options that are widely used. These include simple timers and counters, chip-level and board-level computers, programmable logic controllers, and pneumatic sequencers.

Basic types

Industrial motion control can be divided into four categories: sequencing, speed control, point-to-point control, and incremental motion.

Sequencing refers to the control of several operations so that they all occur in a required order. Perhaps the simplest example of sequential motion is the progression of events that take place through the mechanical linkages of a player piano. When a player piano plays a tune, holes in a paper roll initiate actions that cause piano wires to be struck in a specific sequence. Similarly, actions such as the opening and closing of valves can be sequenced mechanically through the use of cam shafts.

Sequencing generally becomes too complicated to be handled mechanically in the control of industrial equipment such as conveyor lines, or the control of process machines such as fryers in fast-food restaurants. The key quality that makes these *sequencing* applications is a need for move-and-stop, on-and-off control of events that must take place in a certain progression. Factors such as soak time or the position of material on an assembly line determine when operations should start and stop.

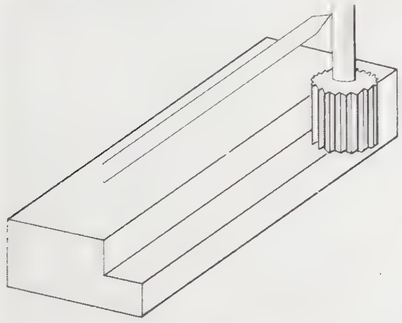
For example, consider a conveyor line that moves parts under construction from one assembly station to another. The controller might position a part at one station until a human assembler punches an "advance" button. This might start the part moving to the next station. Here it might enter a cleaning bath for a programmed soak time. At the end of this period, it might move to a new station for final assembly, and so forth.

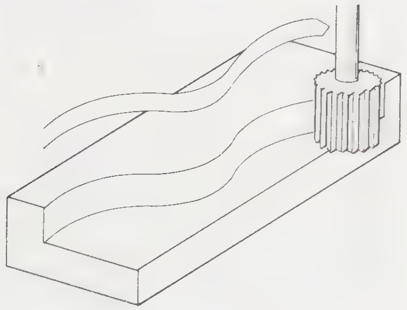
This sort of timing and sequencing is handled through pneumatic, electronic, or electromechanical controllers. Of these, electronic and electromechanical controls are most common. For simple on-off control, timers and counters may suffice. These devices contain sets of electrical contacts that can be opened and closed at time intervals that an operator either enters on a keypad or sets with switches. Counters are similar devices that actuate contacts when a count reaches a preset number. The count increments or decrements when sensors such as proximity switches or limit switches sense an object.

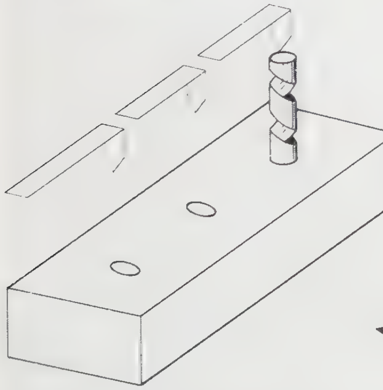
When a sequencing operation consists of more than a few steps, more elaborate controls become necessary. These controls can take the form of discrete elements such as time-delay relays that act in response to input signals from sensors and switches. Over the past two decades, use of numerous relays for sequencing has increasingly given way to programmable logic controllers (PLCs).

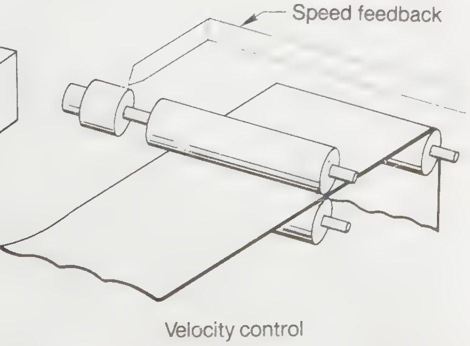
PLCs contain computers that synthesize actions such as timing and counting to sequence operations. The advantage PLCs have over banks of relays is that a PLC can be simply reprogrammed to provide different se-

MAJOR CATEGORIES OF MOTION CONTROL


Single-axis point-to-point


Two-axis contouring


Two-axis point-to-point



Velocity control

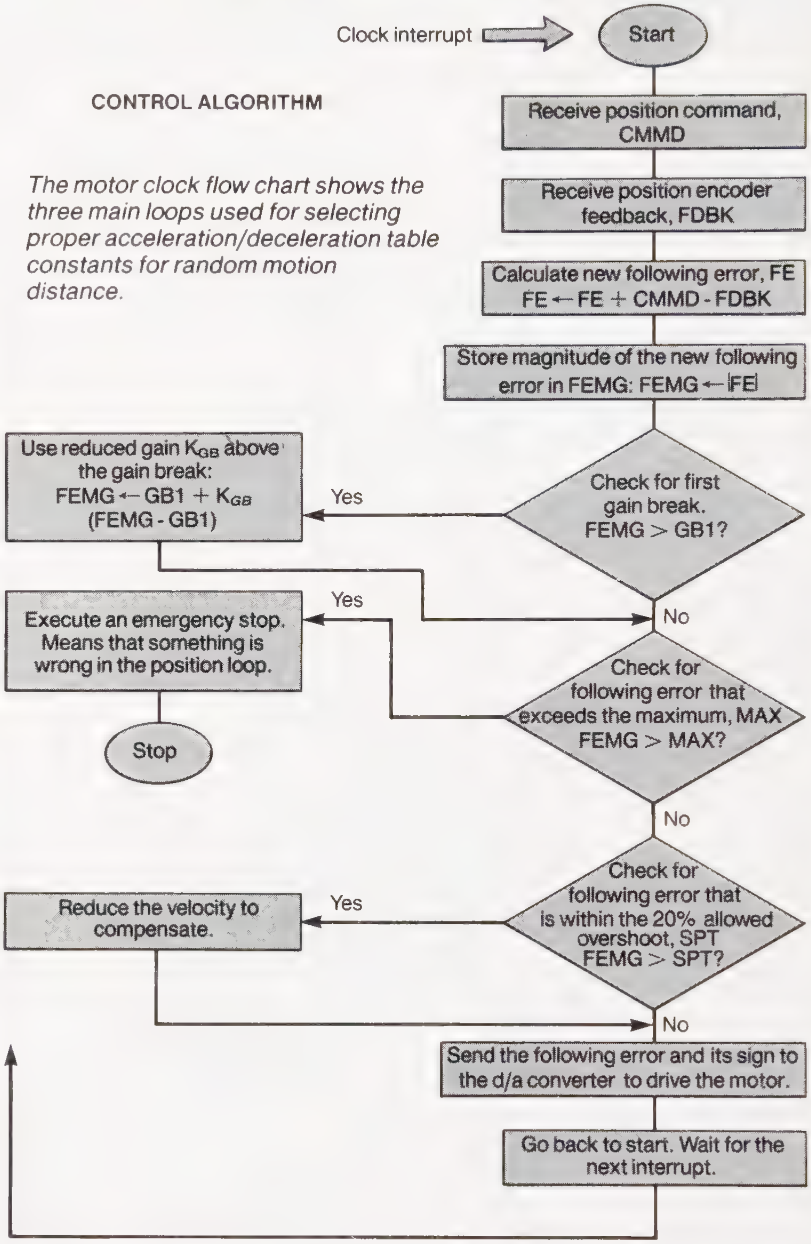
quences and different timing intervals. In contrast, changes made to sequences controlled only by relays may require physical rewiring and reconfiguring, a process that can be time consuming and expensive.

Speed control refers to applications involving machines run at varying speeds or torques. The source of power for such applications is generally either an internal combustion engine, or an electric, hydraulic, or pneumatic mo-

BASIC SERVOCONTROL ALGORITHM

Typical software contouring position-loop execution for systems with a base gain of one is shown in this flow chart. The loop executes once every few milliseconds, as set by the sampling time for the system. The microcomputer executes the program every time it receives a clock pulse from the proper device. At the conclusion of the loop, the program automatically goes back to the beginning to await another clock signal.

In contouring servosystems, servo velocity is often related to following error by a piecewise linear curve usually consisting of two or more straight lines. The slope of these lines is the position-loop gain. Each point where the slope of the line changes is called a "gain break." The number of gain breaks required is set by the performance desired in the servo. Many applications require no gain breaks.



CONTROL ALGORITHM

The motor clock flow chart shows the three main loops used for selecting proper acceleration/deceleration table constants for random motion distance.

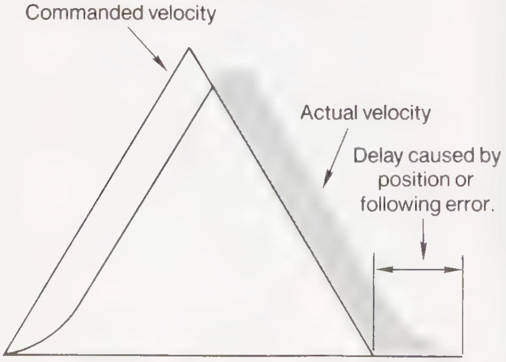
Clock interrupt
Start
Receive position command, CMMD
Receive position encoder feedback, FDBK
Calculate new following error, FE
FE ← FE + CMMD - FDBK
Store magnitude of the new following error in FEMG: FEMG ← |FE|
Check for first gain break. FEMG > GB1?
Yes
Use reduced gain K_{GB} above the gain break: FEMG ← GB1 + K_{GB} (FEMG - GB1)
No
Check for following error that exceeds the maximum, MAX FEMG > MAX?
Yes
Execute an emergency stop. Means that something is wrong in the position loop.
Stop
No
Check for following error that is within the 20% allowed overshoot, SPT FEMG > SPT?
Yes
Reduce the velocity to compensate.
No
Send the following error and its sign to the d/a converter to drive the motor.
Go back to start. Wait for the next interrupt.

The variation in position gain defined by the gain curve allows the servo to operate with adequate stability and limited acceleration at high velocities. When the servo has to move quickly (as when a machine tool travels through air from one cut to another), the system following error increases to a point beyond the gain break. Past the gain break, an increase in velocity allows a larger increase in following error.

It is preferred practice to have the microprocessor position-loop software limit the maximum velocity commanded to the drive by checking limit conditions on the following error. This can prevent machine damage in the event of a feedback loss. For example, if the servo is installed or the feedback unit malfunctions, pulses will only be added to the following error because no feedback pulses are being subtracted from the accumulated error. The accumulator will build up a larger and larger number, perhaps until it overflows the d/a converter.

To account for such conditions, the position-loop software can check for two following-error limits. When the following error exceeds the first limit, the interpolator reduces the velocity command to slow the servo. If following error continues to increase and exceeds the second limit, the position-loop program tells the drive to stop and notifies the system that an error has occurred.

RESULTING COMMANDED AND ACTUAL VELOCITIES



Motion Control
Products
from
INDUSTRIAL
DRIVES

A KOLLMORGEN DIVISION

201 Rock Road, Radford, Virginia 24141
(703) 639-2495 / FAX 703-731-0847

Circle: 108

INTRODUCING A NEW **GOLD**LIN

A Digital Based Servo Amplifier/Positioner

The BDS5 is a full-featured, high-performance brushless positioning servo in one compact enclosure—it is the smallest, totally integrated package available to motion control users. The BDS5 combines a positioner, a servo amplifier, and an I/O interface into one unit. The BDS5 sets new standards for motion control with its simple BASIC-like command structure and sophisticated decision-making capability. The BDS5 provides the same outstanding servo performance that you have come to expect from INDUSTRIAL DRIVES. By using a high-performance 16-bit microprocessor, the BDS5 does not have to compromise on either positioner software or servo performance. This single microprocessor closes all servo loops, resulting in a truly integrated positioning system. The BDS5 has the features and performance you need in your next positioning servo.

BDS5 FEATURES

The BDS5 offers a wide feature set to accommodate real world positioning requirements:

- LOW COST
  The BDS5 is very affordable—even though it is full of advanced features. Use all or only a portion of these features to accomplish your application.

- EASY TO INSTALL
  The BDS5 positioner is easy to install because the servo amplifier and the positioner are integrated into one package. Many interconnects, including the tachometer and encoder, are eliminated.

- SIMPLE PROGRAMMING LANGUAGE
  The BDS5 uses simple BASIC-like commands such as RUN, GOTO (for branching), and GOSUB / RETURN (for subroutines). In addition to a simple comparison statement, advanced IF / ELSEIF / ELSE / END IF statements result in more readable and less error-prone programs. You can comment every line in your program.

- ADVANCED MOTION CONTROL MOVES
  The simple language does not prevent you from solving complex problems. The BDS5 has separate acceleration and deceleration rates as well as linear, half S-curve, and full S-curve acceleration profiles. The BDS5 has Macro Moves for applications where simple indexes cannot do the job. A Macro Move is a combination of up to 30 accelerations, traverses, and decelerations which are fully precalculated for extremely fast execution. The BDS5 has a rotary move for circular table applications.

- MULTITASKING
  The BDS5 provides several levels of multitasking control. This includes a monitor and debug level, three hardware or software alarms, a serial alarm, the main program, and a display update task.

Circle: 1082

- MASTER SLAVE/ELECTRONIC GEARBOX
  The electronic gearbox is used to link two motors together so that the velocity of the slave is proportional to the velocity of the master. The ratio can be from 32767:1 to 1:32767 and can be negative to allow the slave to move in the opposite direction. Also, the "index-on-gearing" feature permits phase adjustments while in motion.

- MASTER SLAVE/PROFILE REGULATION
  With profile regulation, you can control the slave's motion profile according to an external master motor or frequency. Profile regulation modifies the velocity and acceleration of the slave axis without affecting the final position of the move. You can use profile regulation to implement "feed rate override."

- MOTION GATING AND REGISTRATION
  The BDS5 can precalculate moves to begin motion within one millisecond after a transition on the GATE input. This input provides rapid and repeatable motion initiation. The BDS5 has the ability to capture the current position within 25μsec after a transition of the HOME input, resulting in fast homing and accurate registration sequences.

- ARITHMETIC
  Algebraic math is provided for commands such as:
  $$X1 = 2 \cdot (X2 + X3)$$
  The BDS5 has 500 program labels, 250 user-definable variables, and 50 user-definable switches. It also has 15 arithmetic/logical operations and over 150 system variables.

- USER UNITS
  Quantities such as position, velocity, acceleration, current, external position, and external velocity are automatically scaled into user-definable units. This feature lets you program the BDS5 in convenient units such as feet, inches, mils, RPM, and degrees.

- SUPERIOR SERVO LOOP CONTROL
  The BDS5 offers smooth, high-resolution control. Standard BDS5 position repeatability is better than one arc-minute, bidirectional. Higher resolution systems get even better. The BDS5 has a 32-bit position word. The BDS5 position loop completely eliminates the digital dither normally associated with positioning systems. Long-term speed stability is 0.01%. The

FAMILY MEMBER – THE BDS5

the BDS4 Analog Based Servo Amplifier

standard system converter (12 bit) provides a resolution of 0.0005 RPM and a maximum speed of 8000 RPM. Higher resolution options are available.

- SELF-TUNING
  The BDS5 can tune itself. You do not have to be a servo expert to set up a system fast. Just specify the desired bandwidth, and let the BDS5 do the rest.

- POWERFUL MICROPROCESSOR
  The heart of the BDS5 is the 16-bit processor that delivers high performance. The result: the BDS5 can control a motor and execute its motion program faster than a standard positioner can execute its motion program.

- DIGITAL SERVO LOOPS
  Both the position and velocity loops are totally digital. The digital loops give the BDS5 features not available in standard velocity drives such as self-tuning, very low velocity offset, and digitally adjustable servo tuning parameters. The optional analog input permits you to use the BDS5 as an analog velocity drive, and the optional pulse input allows the BDS5 to accept stepper motor commands.

- FEED-FORWARD GAIN
  The digital feed-forward gain reduces following error and motion initiation delay to increase machine throughput.

- DIAGNOSTICS
  The BDS5 offers a complete set of error diagnostics. When an error occurs, the BDS5 displays an English language error message. The BDS5 remembers the last 20 errors even through power loss. In addition, the BDS5 lets you write your own error handler. During a fault condition you can use the error handler to set outputs, alert an operator, and shut down your process smoothly. The BDS5 offers trace and single step modes so you can debug your program. The BDS5 has complete fault monitoring including overtravel limit switches, feedback loss, software position limits, as well as hardware safety circuits (watchdogs) and checksums for more reliable and safer operation.

- I/O
  The BDS5 has up to 32 I/O sections that you connect via ribbon cable to standard OPTO-22 compatible I/O boards or to INDUSTRIAL DRIVES I/O-32. The I/O-32 provides either fixed 24-volt or removable industry standard optically isolated I/O in a **GOLD**LINE style package.

- SERIAL COMMUNICATIONS
  The BDS5's serial communications provide a powerful link to other popular factory automation devices such as PLCs, process control computers, and smart terminals. The BDS5 offers RS-232 for most terminals or RS-422/RS-485 for multidrop communications. With multidrop you can put up to 26 axes on one serial line. The BDS5 can auto-baud from 300 baud to 19.2k baud eliminating the need to set dip switches to start communicating.

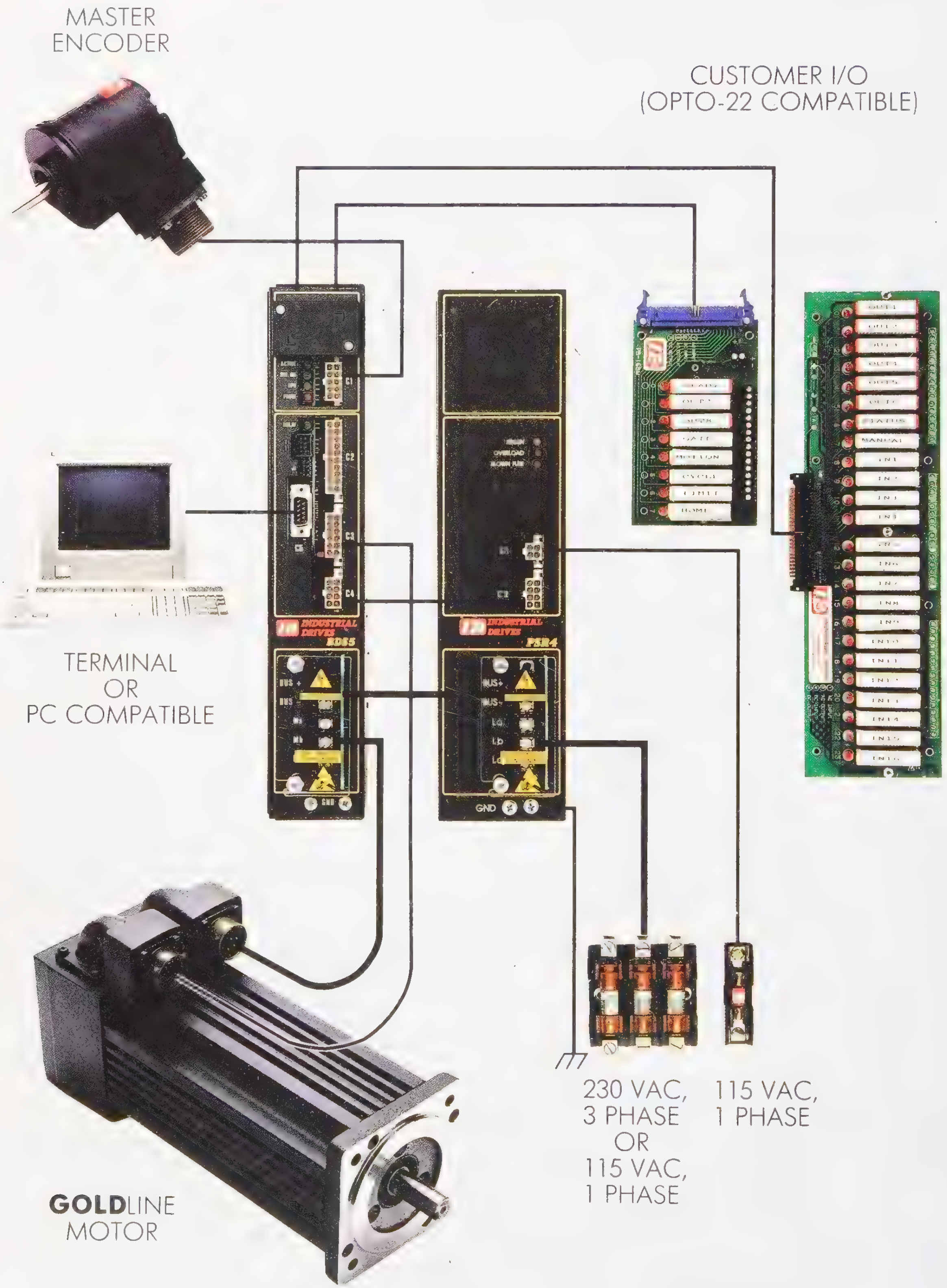
- MOTION LINK
  INDUSTRIAL DRIVES also offers MOTION LINK, a powerful, menu-driven communications package for your IBM PC compatible computer. With this package the BDS5's programs and variables can be received from or saved to a disk drive. There is also on-line help and a full screen editor built into MOTION LINK.

- MENU-DRIVEN SOFTWARE
  The BDS5's programming language allows you to write operator-friendly, menu-driven software. By incorporating the INDUSTRIAL DRIVES Data Entry Panel or any other serial communications device, the operator can be prompted for specific process data. You can also program teach modes where position end points can be changed by the factory operator.

- MONITOR MODE
  The BDS5 provides interactive communications and permits all system variables and parameters to be examined and modified at any time—even during program execution or while the motor is running.

ID INDUSTRIAL DRIVES
A KOLLMORGEN DIVISION
Circle: 1083

TYPICAL BDS5 SYSTEM INTERCONNECT


MASTER ENCODER
CUSTOMER I/O (OPTO-22 COMPATIBLE)
TERMINAL OR PC COMPATIBLE
BDS5
PSR4
C1
C2
C3
C4
GOLDLINE MOTOR
230 VAC, 3 PHASE OR 115 VAC, 1 PHASE
115 VAC, 1 PHASE

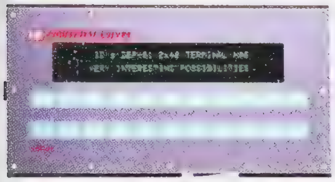
INDUSTRIAL DRIVES
A KOLLMORGEN DIVISION

Circle: 1084

OPTIONS

BDS5 COMMUNICATIONS PROGRAM

The BDS5 Communications Program (MOTION LINK) provides an intelligent communications link between the BDS5 system and any IBM PC© compatible computer. This program provides the ability to receive programs and parameters from the BDS5 to the PC's disk drive as well as transmit programs and parameters to the BDS5 from the PC's disk drive. Additionally, this program provides a full screen editor and on-line help.



DEP-01 DATA ENTRY PANEL

The DEP-01 Data Entry Panel measures 286x146x64mm (11.25"x5.75"x2.50") and provides a two line by 40-character vacuum fluorescent display and 22 factory-definable keys into a sealed, panel mount package. The DEP transmits and receives standard ASCII serial data at 9600 baud. The DEP-01 requires 115 volts AC. An RS-485 option is available for communications with multiple BDS5 axes.

HAND-HELD TERMINAL

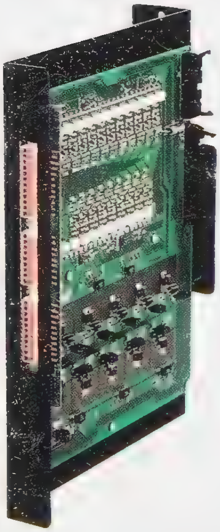
The Hand-Held Terminal measures 178x102x25mm (7"x4"x1") and provides a four line by 20-character backlighted LCD super twist display and a 45-key ASCII keypad. This device is useful for many functions including program entry and editing, and manual operations of the positioner and diagnostics.

RS-422/RS-485 MULTIDROP COMMUNICATIONS OPTION

The BDS5 is standardly configured with RS-232 serial communications that can communicate with one external device. This can be replaced with the RS-422/RS-485 Serial Communications Option that will allow up to 26 axes on one serial line.

I/O EXPANSION OPTION

The I/O Expansion Option adds 24 additional I/O lines to the BDS5's basic 8 I/Os. These 24 I/Os include: MANUAL, STATUS, IN1-IN16, OUT1-OUT6. The I/O Expansion Option is required with both of the **GOLD**LINE I/O Interface Options.



GOLDLINE I/O INTERFACE OPTIONS

The **GOLD**LINE I/O interfaces provide 22 optically isolated inputs and 10 optically isolated outputs in a **GOLD**LINE electronic package. The footprint of the **GOLD**LINE I/O interface is 100% smaller than the equivalent OPTO-22© compatible mounting racks. Status LEDs are provided directly above wiring points to allow for easy system diagnosis.

- The I/O-32-24V interface provides 32 discrete 24 VDC optically isolated I/O sections. This interface provides a low cost, highly reliable electronics package using surface-mounted technology.
- The I/O-32-OPTO interface will accept 32 industry standard optical isolation modules. The industry standard I/O modules allow for easy field repair and accept a wide range of input and output voltages. This interface allows I/O modules with voltages up to 60 volts DC and 140 volts AC.

ANALOG INPUT OPTION

The BDS5 is standardly configured with a quadrature encoder input that can be replaced with the analog input option. This option provides a ± 10-volt differential analog input to the BDS5. This input can be used with the profile regulation master/slave mode. The analog input option can also be used to command a velocity or current. The encoder equivalent input can be directly connected to any standard +5-volt encoder and can also be connected directly to another BDS5's encoder equivalent output.

PULSE INPUT OPTION

The BDS5 can also be configured with a pulse input option. This option, like the analog input option, replaces the quadrature encoder input and provides three types of inputs: count/direction, up/down, and single phase.

OTHER OPTIONS

Other BDS5 options include side covers, position feedback resolution, motor output voltage and current, power supply voltage and current, regen, soft start, and dynamic braking.

Circle: 1085

tor. Speed can be controlled either mechanically or, in the case of electric motors, electronically.

Mechanical speed-control components include clutches and brakes, adjustable-speed drives, traction drives, transmissions, and fluid-coupled drives. There are also electromechanical and hydraulic devices that are essentially electrically or hydraulically actuated mechanical clutches and brakes.

Examples illustrating where such technologies are used include web presses, filament-winding machines, and feedstock applications. Slip clutches and brakes are commonly used on the axes of web rolls, filament-winding mechanisms, and on lumbermill saws to stop rotating components quickly. Mechanical adjustable-speed drives are frequently employed to vary the speed at which stock is fed into a processing operation or conveyor line. One instance occurs in chemical processing, where the rate at which feed stock enters processing must change from day to day depending on environmental factors such as ambient temperature and humidity.

Other mechanical motion-control devices commonly include gears, belts and chains. These provide a means of changing applied torque and velocity.

In contrast to mechanical speed-control technology, which usually employs gearing or belts to change speed, electronic speed control manipulates applied electrical power to control velocity and torque. Electronic speed control in ac motors employ special amplifiers or drives. These generally vary ac motor speed with adjustable-frequency inverters. Though such electronic controls are more expensive than mechanical speed controls, they provide the advantage of reduced energy costs. Applications for such equipment include fans, blowers, pumps, and compressors.

Adjustable-frequency inverters of a different type are also used to control the speed of dc motors. Dc motors have been preferred over ac motors for adjustable-speed applications because dc motors tend to cost less. However, ac variable-speed drives are often preferred for equipment that is frequently started, stopped, and reversed, especially in hostile environments. Ac drives are also widely used for multimotor applications that require precise speed matching. Both ac and dc variable-speed motors are used in manufacturing applications such as spindle drives where appreciable amounts of torque are required at relatively high rotational speeds.

Point-to-point motion control, in contrast with velocity control, generally refers to applications where something must move from one point to another at a constant speed. An important requirement in such applications is that there are two factors that must be controlled, speed and distance. Examples of point-to-point movement are in *x-y* tables and in machining, where a tool moves in a straight line while it touches a work face along one axis.

Because such applications demand monitoring and control of both velocity and position, they need a controller to keep track of system operating conditions at any given time. This controller can be either hardwired electronic logic, a computer, or a PLC.

In general, the simplest positioning system of this sort might be found on older milling machines. These contain an *x-y* positioning system for moving the fixture holding the workpiece. The positioning system involves ac or dc motors, an adjustable-speed drive, clutch, and a position transducer that reads out the position of each table axis. The positioning mechanism for such a system is usually a ball screw.

Many systems for point-to-point positioning use a stepping motor which is considered particularly well suited for this type of application. Stepping motors work from electrical signals that are pulses. The stepping-motor shaft moves through a specific angle in response to each input pulse. This allows it to rotate in fixed, repeatable, known increments, unlike conventional motors.

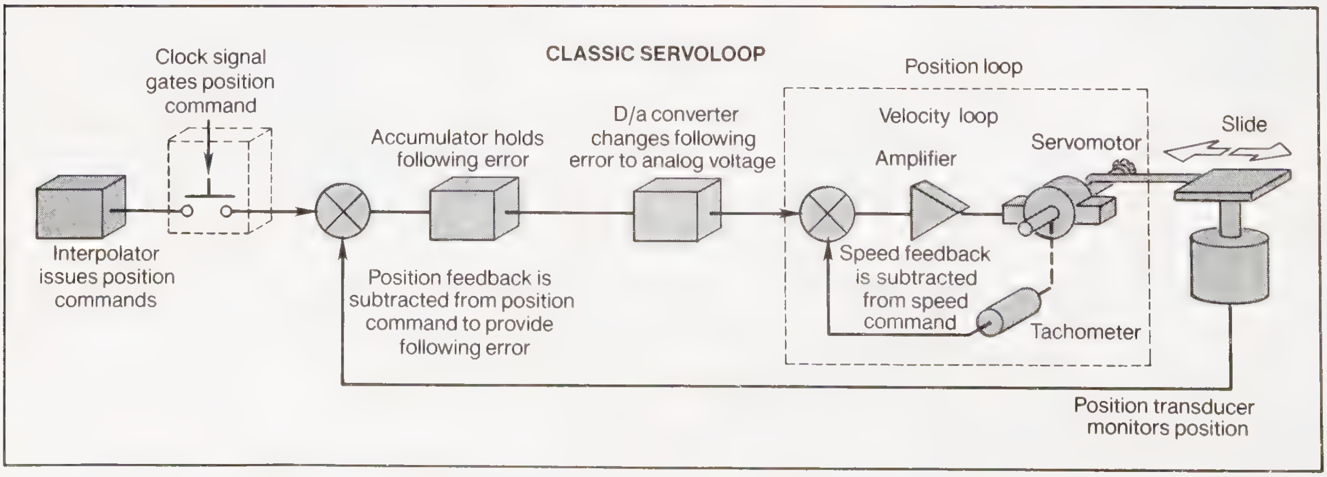
Stepping motors are useful in motion control because they can move an object a given distance simply by rotating for a preset number of pulses. Thus, to obtain a move of a given distance, a controller sends a given number of pulses to the stepping motor. Motor velocity is controlled by varying the pulse rate.

The majority of stepping-motor positioning applications use a computer to generate the move commands. The basic approach to generating a motor step via software is to first determine the required step rate, then calculate the time period needed between the steps occurring at this rate. The computer is then programmed to count this period before it sends a step signal to the motor.

Stepping routines generate signals that command electromagnets in the stepping motor to move the rotor one step. By switching the signal polarity, magnets on the rotating shaft are drawn into magnetic alignment, causing a one-step rotation of the shaft.

The most common variety of stepping motor employs two windings to generate electromagnetic fields in the stator. Thus, two control signals must be generated to power these two-phase motors. Software stepping routines generally use lookup tables to match signals of the proper polarity with the corresponding winding.

Similar techniques are used to obtain microstepping of the stepping motor. Microstepping comes about by applying varying voltage levels to the mo-

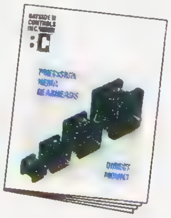

CLASSIC SERVOLOOP
Clock signal gates position command
Interpolator issues position commands
Accumulator holds following error
Position feedback is subtracted from position command to provide following error
D/a converter changes following error to analog voltage
Position loop
Velocity loop
Amplifier
Servomotor
Speed feedback is subtracted from speed command
Tachometer
Slide
Position transducer monitors position

BAYSIDE Precision Gearheads

THE CHOICE IS YOURS

NEMA Spur Gearheads

Bayside NEMA Spur Gearheads offer high precision, low backlash, and very high efficiency, in a compact inline package. These NEMA Gearheads offer the flexibility of a complete range of ratios and sizes, provided ready-to-mount to standard NEMA-face stepper and servo motors. Bayside's Clamp-On Pinion, combined with a wide variety of different motor-mounting packages, makes it easy to attach our NEMA Spur Gearheads to many different motors.



Planetary Gearheads

Bayside Planetary Gearheads provide high torque, low backlash, and high efficiency, in a compact, inline package. With Bayside's Clamp-On Pinion, the Planetary Gearheads mount directly to the face of a wide variety of servo and stepper motors. Available in five frame sizes, and multiple ratios, Bayside Planetary Gearheads are a high performance solution to your gear reduction needs.

Right Angle Planetary Gearheads

Bayside's new Right Angle Planetary Gearheads provide the same high performance features as Bayside's Planetary Gearheads, in a space-saving right angle configuration. High efficiency, high torque, and low backlash are all provided, in five different frame sizes. Bayside's exclusive Clamp-On Pinion makes it easy to attach our Right Angle Planetary Gearheads to a wide variety of servo and stepper motors.

Bayside Gearheads mount to motors from the following companies (Partial list):

AEROTECH
ALLEN-BRADLEY
AMERICAN PRECISION
ANAHEIM AUTOMATION
BALDOR
BEI
BODINE
CLIFTON
CMC TORQUE SYSTEMS
COMPUMOTOR
CONTRAVES
EASTERN AIR DEVICES
EMERSON
FANUC
GETTYS
GIDDINGS & LEWIS
  (NEXES AUTOMATION)
GME
HITACHI
HONEYWELL
INDRAMAT
INDUSTRIAL DRIVES
INFRANOR
INLAND MOTOR
INTELLICO
LEESON
MAGNETEK
MAXON
MFM
MODICON
MOOG
MTS
NYDEN
ORIENTAL MOTOR
ORMEC
PACIFIC SCIENTIFIC
PARVEX
PITTMAN
PMI
PORTESCAP
RELIANCE MOTION CONTROL
  (ELECTRO-CRAFT)
SIEMENS
SUPERIOR ELECTRIC
TOSHIBA
VICKERS
WHEDCO
YOKOGAWA
YASKAWA

Our experienced engineers are ready to answer your application questions. For application help, or for a color catalog call:

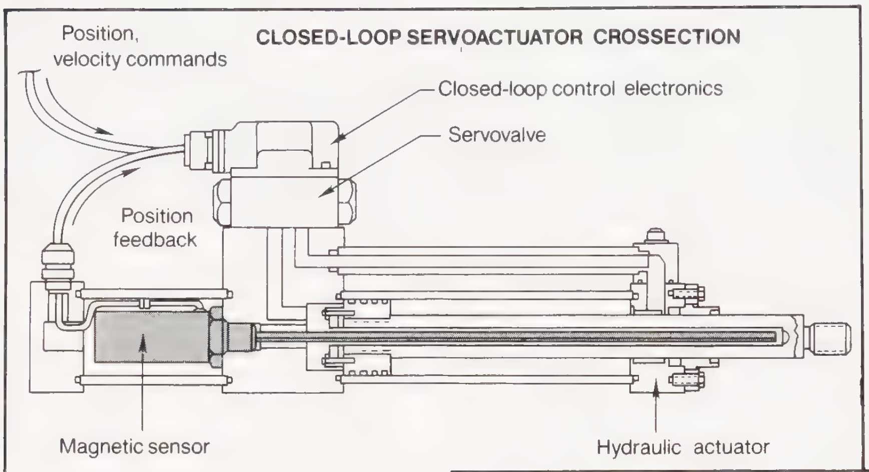
BAYSIDE CONTROLS INC. • 27 SEAVIEW BOULEVARD • PORT WASHINGTON, NY 11050
TEL: (516) 484-5353 • FAX: (516) 484-5496

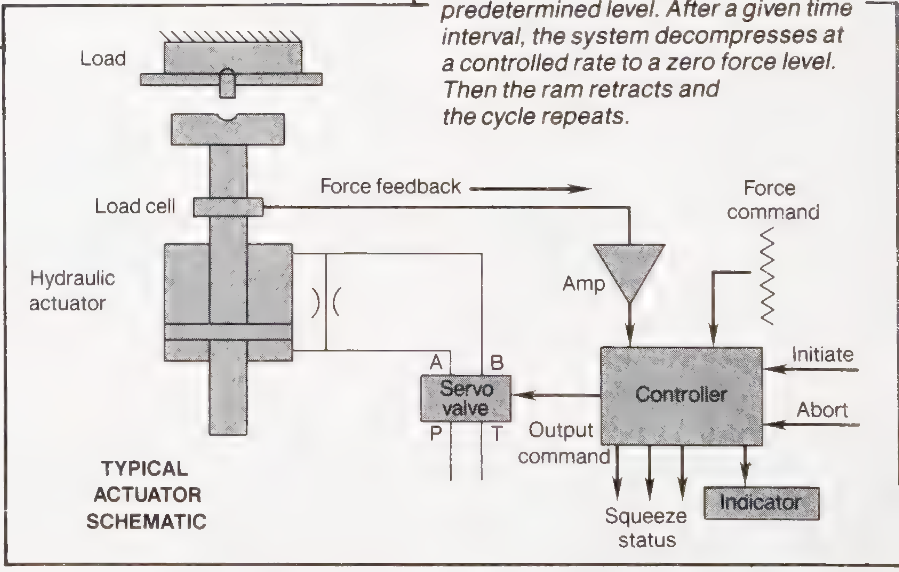
BAYSIDE CONTROLS INC.
BCI

Circle 101

tor coils. These voltage levels normally range from zero to the full step voltage. Sequencing the voltage levels positions the motor shaft to be positioned at intervals that are smaller than a full step.

Most motors, regardless of type, usually require controlled acceleration and deceleration for best response, especially when the motor moves a load having significant inertia. To obtain this acceleration and deceleration in stepping motors, controllers use a technique called motor-clock ramping where the frequency of the control pulses are varied to accelerate the motor from zero to maximum speed. This variable motor clock rate is often generated through software. The computer controls the time period between control pulses using precalculated constants stored in memory tables. These constants may be optimized empirically by running various motor velocity vs. time trials.


CLOSED-LOOP SERVOACTUATOR CROSSECTION


TYPICAL ACTUATOR SCHEMATIC

Combination servovalve/controllers can accept serial commands from controllers such as PLCs. On-board electronics handle closed-loop servocontrol for positioning a hydraulic actuator, using feedback from some sort of transducer. An example application is in riveting. Here, force is the controlling variable. Feedback comes from a load cell that measures applied force. A ram advances under open-loop servocontrol until it hits the rivet. At the instant of contact, force starts to build up and the system switches to closed-loop control. This allows force to increase at a controlled rate to a predetermined level. After a given time interval, the system decompresses at a controlled rate to a zero force level. Then the ram retracts and the cycle repeats.

No motor acceleration profile can satisfy all applications. However, a step rate that follows an exponential curve is often adequate. The exponential curve used to generate acceleration/deceleration profiles is defined by

$$V = V_I + \frac{(V_F - V_I)(1 - e^{-T/S_K})}{1 - e^{-T_F/S_K}}$$

where V = step rate, V_I = starting step rate, and V_F = final step rate (all in steps/s), S_K = shape factor, T = time in s, T_F = final time to complete the acceleration to V_F, and e = base of the natural logarithm.

The starting step V_I rate can usually be determined from motor torque vs. speed characteristic curves. The torque required to accelerate a given load is first calculated. Then the maximum usable motor velocity (called the start-stop rate) at that torque is read from the motor curves. Using approximately one-third of this value generally provides a reliable starting frequency.

The maximum usable step rate can be determined by testing the motor and driver circuit. The motor test is conducted with the motor connected to the actual load or to an equivalent load representing load inertia. A pulse generator supplies motor-control pulses. To determine the step rate, the generator frequency is slowly increased to a point just before the motor stalls. Using 80% of this frequency generally provides reliable high-speed operation.

The shape factor determines the general rate of change of motor acceleration. For example, a small shape factor produces steep initial acceleration, whereas a large factor produces nearly linear acceleration. The shape factor for the exponential equation described can vary from 0.005 to 0.5.

The same basic equation used for acceleration tables can generate deceleration tables. However, stepping motors can generally decelerate in 10 to 20% less time than they can accelerate, and equation variables can be adjusted accordingly. When a stepping motor reaches the final step in deceleration, the motor shaft may oscillate before the load settles down. This settling time depends on the motor type, load, and motor drive. Settling time can be reduced by selecting the deceleration profile and motor velocity (stopping frequency) through empirically testing various profiles.

Once acceleration/deceleration tables have been stored in memory, a software routine uses the table values to generate motor-control pulses at proper frequencies. The routine selects the acceleration/deceleration constants that will give the quickest moves over a given distance.

Incremental motion control can be contrasted with point-to-point control by first examining some of the shortcomings of systems powered by the latter approach. In the simplest case, a point-to-point system moves a commanded distance. But for some applications, simply commanding the motor to move a prescribed distance does not provide enough accuracy. Machine

WHAT'S BEEN PROVEN FOR OVER ONE HUNDRED YEARS?

That DODGE®, MASTER® and REEVES® products give you quality, value and dependability. That's been proven by you — American industry.

We supply the unit and bulk material handling and processing industry with everything from drive com-ponents to controlled start transmissions. And we do it with proven performers such as the DODGE Type E Roller Bearing and TORQUE-ARM Speed Reducer. We also bring you innovative, new products such as the REEVES MAS 51, the latest mechanical adjustable speed drive, and the DODGE S-2000, the one that's going to make all other setscrew spherical bearings virtually obsolete.

And we stand behind our products with people that have the technical expertise that sets the industry standard. We've been doing it for over a century.

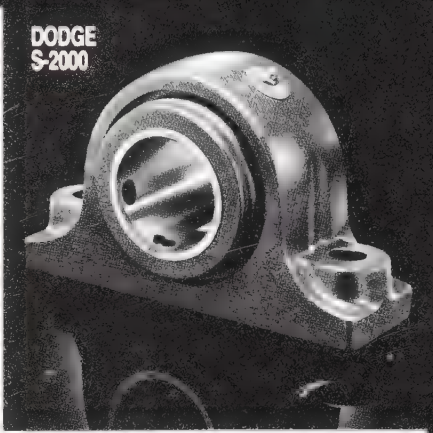
Specify DODGE, MASTER, REEVES.

DODGE®

Move faster with the leader.™

DODGE
Type E

DODGE TIGEAR®
Speed Reducer


DODGE
S-2000

DODGE
TORQUE-ARM
Speed Redu

DODGE
TAF-XT

REEVES
MAS 51

DODGE
TAPER-LOCK®
Sheave & Bush[illegible] System

DODGE
PARA-FLEX®
Coupling

DODGE
APG
Gearmotor

For more information, call 1-803-297-4800, or see your local DODGE • MASTER • REEVES distributor in the yellow pages.

RELIANCE ELECTRIC

Circle 102

DODGE® software selects and draws

Choose the best alternative in only minutes.

DODGE SOFTWARE™

If you're still paging through monstrous catalogs to select your DODGE Products, then taking hours drawing those components, you're spending too much time–and brain power–on unnecessary grunt work. There's a faster way. DODGE has taken the grunt work out of *your* work and put it into our *new* DODGE SOFTWARE™ package. With DODGE SOFTWARE we virtually eliminate manual selection and drawing of DODGE Products.

DODGE SOFTWARE Product Selection Library allows you to cut your selection process from hours to minutes. And there's no time-consuming calculating that can cause errors. Just enter parameter data (such as weight, load, speed, distance, etc.) on the user friendly screen. Your PC does all the rest, quickly and accurately. Without any grunt work, you're given multiple correct selections to choose from. You even get pricing information w some programs. The DODGE SOF WARE Product Selection Library includes the following programs:

APG DISCovery™. Quickly match drive requirements with specific DODGE APG Gearmotors and Reducers. Includes pricing.

BEST™. DODGE Bearing Evaluat and Selection Technique. Calcula load, fatigue life and heat transfer analysis based on input paramete for mounted ball and roller bearing

CONVEYOR™. Provides detailed design information while selecting DODGE conveyor components fo horizontal or inclined conveyors w minimal input.

COUPLE™. Provides nine DODG shaft coupling alternatives. Select specific coupling for any applicati or gives recommendations based your specific application. Includes ship weights and pricing.

FHPD™. Fractional Horsepower V-Drive Product Selection. Selects and prices 10 best DODGE fractio horsepower V-Drive alternatives.

REEVES® DISCovery™. Selects REEVES MOTO DRIVES®, MAS-5 ULTIMA™, and SCREWDRIVER™ Mechanical Adjustable Speed Drives. Includes pricing. Available 3rd quarter 1992.

⋆**RTLXC**™. Selects RTL or XC SLEEVOIL® bearings. Options include analysis as a plain, air cooled, water cooled or circulatin oil bearing.

⋆**RXTPC**™. DODGE sleeve beari selection. Analyzes plain bearing converts to water cooling or to circulating oil. Makes evaluations with either SAE or ISO oils. for bo RXT-S and RXT-T designs.

automatically DODGE® products.

CD DISCovery™. Provides simple ethod of applying and selecting crew Conveyor Drive Speed educers. Can share data with A-VISA® or VIA-SYNC™ programs.

A DISCovery™. Provides easy eans of applying and selecting ODGE TORQUE-ARM™ Gear educers. Given accurate service ctor input data, the program atches your drive requirements with specific TORQUE-ARM product. an share data with VIA-VISA or IA-SYNC programs.

A-DS SHELL™. Combines the election of a TORQUE-ARM Gear educer or Screw Conveyor educer with the sizing of a V-drive synchronous belt drive system. ombines the capabilities of these ur DODGE product selection rograms:

A DISCovery™ → VIA-VISA®
CD DISCovery™ → VIA-SYNC™

XL DISCovery™. Quickly applies nd selects DODGE TIGEAR® educers and MASTER® XL earmotors and Reducers. Includes ricing.

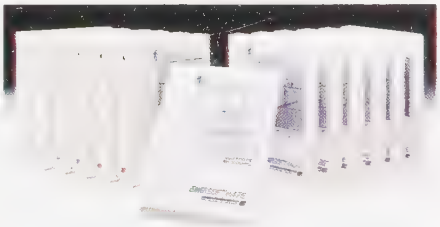
IA-SYNC™. Provides user with the 0 best HTD+ or DYNA-SYNC® drive elections. Also provides selections r both TAPER-LOCK® and QD* yle sprockets. Can share data with CD DISCovery or T-A DISCovery rograms.

IA-VISA®. V-Drive Instant Selection nalysis. Selects and prices 10 est DODGE V-Drive alternatives. ncludes TAPER-LOCK and QD yle sheaves. Can share data ith T-A DISCovery or SCD ISCovery™ programs.

It is now possible to share data between RTLXC and RXTPC.

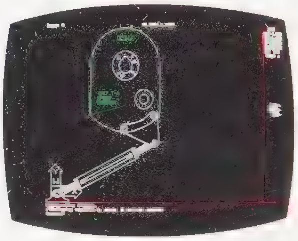
1ˢᵗ LINE®
Electronic Templates for Design

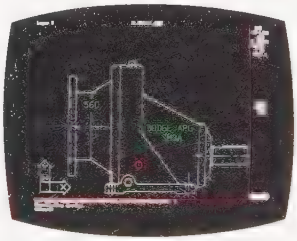
Let FIRST LINE® do your drawings for you.



Now you can draw on the resources of DODGE with the FIRST LINE® system of AutoCAD® drawings. Also available in DXF™ format. Just tell your CAD system which DODGE Products you want, and that product is transferred to your design drawing. Automatically, in just seven entries from the menu, your PC and FIRST LINE have done all the grunt work for you. The FIRST LINE software is offered as an entire library or in modules that correspond to the same product groupings found in the DODGE Engineering Catalogs. FIRST LINE library includes component drawings in front and side views for:

- DODGE Mounted Ball Bearings.
- DODGE Mounted Tapered Roller Bearings.
- DODGE Mounted Spherical Roller Bearings.
- DODGE Sleeve Bearings and Take-Up Frames.
- DODGE Shaft Couplings.





- DODGE TAPER-LOCK® Sheaves.
- DODGE TIGEAR® Right Angle Reducers. Includes top views.
- MASTER® XL Right Angle Reducers & Gearmotors.
- DODGE MAXUM™ Concentric Reducers. Available 2nd quarter 1992.
- DODGE TORQUE-ARM™ Shaft Mounted Reducers.
- DODGE Screw Conveyor Drives.
- DODGE APG Gear Reducers. Includes top views.
- NEMA C-Face Motors.
- REEVES® Mechanical Adjustable Speed Drives.

Combine the DODGE SOFTWARE Product Selection Library and FIRST LINE drawings and get grunt work out of your life forever.

For quickest ordering, pricing and free 28-page brochure, call 1-803-297-4800. Fax: 1-803-281-2318.

DODGE®

Move faster with the leader.™

Circle 103

RELIANCE ELECTRIC

slippage, distortion, and other factors may prevent the motor from moving the load to point desired.

Closed-loop (sometimes called servoloop) control systems overcome this drawback. They provide precise position control with feedback. Feedback minimizes the difference between the commanded position or velocity of the system and the actual location or velocity. In other words, feedback minimizes position or velocity error.

Closed-loop systems have been constructed around a variety of controlling functions ranging from mechanical displacement to pneumatic or hydraulic pressure. However, solid-state electronics made electrical currents the preferred process variable, though the principles described here can be applied to any closed-loop positioning system. Consequently, electronic closed-loop controls are now built into several different kinds of positioning systems that range from hydraulics and pneumatics to multiaxis web control.

In their simplest form, electronic closed-loop motion-control systems consist of a controller, a motor, an amplifier to drive the motor, and a transducer that monitors motion. The controller sends out position commands periodically in increments set by a clock. These pulses command the drive to move some distance in the next in-

CONSIDERATIONS FOR CLOSED-LOOP HYDRAULICS

Closed-loop control of hydraulics offers excellent positioning accuracy, in many cases matching that of electric servomotor systems. In fact, low inertia, high torque-to-inertia ratio, and high bandwidth allow these systems to outperform their electric counterparts. However, controlling hydraulics poses unique problems not found in electrical positioning systems.

Making these systems work involves delicate interplay between hydraulic components, feedback devices, and electronic controllers. Complicating the situation is the wide variety of choices available in each of these areas, and the fact that many of them work in different ways. Electrohydraulic control involves more than simply selecting a controller and connecting wires. The hydraulic components in a closed-loop system have a great deal to do with overall performance.

Valves: Most hydraulic component manufacturers supply an amplifier card with their valves, and many control companies sell them as well. Such cards, when supplied by a voltage, produce a corresponding valve position. Unfortunately, capabilities of these controls vary widely. Because valve position is not necessarily linearly related to flow rate or cylinder velocity, overall performance may be less than required.

Control systems compensate for shortcomings in proportional controllers and some servovalves in a number of ways. A control system compensates for deadband by initially applying a large voltage to the valve, causing it to move quickly just out of the dead zone. Variable gain is offset by building dual-gain capability into the controls. Setting the system for low gain at high speeds and high gain at low speeds directly counteracts valve gain nonlinearities.

Unfortunately, such compensation does not always eliminate system nonlinearities. A change in oil temperature may change the dead zone, and temperature changes may also cause drift in sensing circuitry. Pressure changes affect valve flow characteristics, and alter the speed at which low to high gain transition occurs. Using these features with a proportional valve results in a workable system, if the valve operates exclusively in the low or high range. If operating at a very low speed, or the gain break point, this may not be the case.

Cylinders and motors: Standard hydraulic cylinders work well in most closed-loop applications. In some cases, stiction can pose serious problems when controlling position to microinches at low speeds. For such applications, cylinders with special seals and low-friction bearings are available.

Most low-cost hydraulic motors, however, suffer from deadband similar to that found in valves. Caused by internal leakage, a certain amount of flow is necessary to overcome the leakage before the motor moves. Precision servomotors are available that eliminate this problem.

Pumps: Fixed or variable-displacement pumps can be used in motion-control applications. Fixed-displacement models always pumps a set amount of fluid, even if no flow is required by the system. These pumps are simple, but often waste energy and unnecessarily heat the fluid.

For this reason, variable-displacement pumps are often used. Although they are more expensive than fixed-displacement models, they use less energy by supplying fluid only when it is needed. However, this causes a problem in closed-loop servosystems. When movement is necessary, there is no opportunity to forewarn the pump. Therefore, fluid is not delivered immediately, causing a response lag in the system. To avoid such problems, an accumulator is necessary to supply fluid until the pump reaches full power.

Filters: System filtration should not be overlooked, because performance of servovalves and motors deteriorates if dirt is present in the fluid. Pressure filters that protect servovalves should be used, and a differential pressure switch on the filter is recommended. The pressure switch senses when the filter is clogged and can be used to signal the controller to shut down the system. Also, prior to initial operation of the system, servovalves should be temporarily replaced with flushing valves, manifold blocks, or other connectors, and the system thoroughly flushed to remove any built-in contamination.

Compressibility: Another consideration is fluid compressibility. Hydraulic fluid is often considered to be incompressible, but it is slightly compressible. Compressibility results in behavior much like that of a spring-mass oscillator. Perturbing a cylinder that is driving a mass makes it resonate at some frequency determined by the volume and compressibility of oil and size of the mass. A high resonant frequency is preferred to minimize overshoot. Low mass, short-stroke, and large-diameter cylinders, and high bulk modulus all result in a higher resonant frequency.

Compensating for fluid compressibility is difficult because it varies, depending on operating conditions. Bulk modulus (the measure of fluid compressibility) is affected by the type of oil, temperature, and air dissolved in the oil. In most applications, entrapped air is the most significant factor.

For this reason, it is advisable to operate a servosystem at high pressure because entrapped air is more likely in a low-pressure system. A good rule-of-thumb is to operate a closed-loop system at 1,000 psi or greater.

Valve location also contributes to system resonant frequency. In most cases, the valve is not built into the cylinder but, rather, is mounted elsewhere. A significant amount of fluid between valve and cylinder lowers the resonant frequency. Mounting the valve directly to the cylinder and using pipe or a manifold, not hose, to connect the ports raises the resonant frequency. Because hose expands under pressure, it increases system compressibility.

Compensating for factors such as temperature, pressure, and compressibility is difficult at best, and in most cases beyond the means of general-purpose motion-control systems. Selecting the proper components, and installing them to avoid the negative effects of these factors is a simpler and more economical approach.

Vital technologies for motion and control

Parker Fluidpower

Industry's Complete Source For Quality Fluidpower Products, Systems, and Service.

Circle 104

Parker...Your Complete Source for Quality Fluidpower Motion Control Products,

Parker's complete line of performance-matched fluidpower components and total systems capabilities represent industry's highest level of engineering and manufacturing skills.

The Parker system... is an international distribution network supported by strategically located manufacturing plants and fully stocked service centers, staffed by trained application and field service people.

World's First And Largest Choice of Hydraulic & Pneumatic Linear Actuators

Parker's standard cylinder line includes: 7 series hydraulic, with the Series "3H" large bore and "Parkertronics" linear position and velocity sensing system; 8 series pneumatic, with Parker's Series "SR" stainless round steel body air cylinders, piston and bladder type accumulators... *Plus* specials to meet your specific application. Innovative features include: exclusive Jewel Rod Gland with extrusion-proof no-leak seals, hydraulic stepped cushions to reduce shock up to 90% and decrease cushioning time up to 50%, Hi Load pistons for virtually zero leakage, non-lube and prelubricated air cylinders for millions of trouble-free cycles without added lubrication; and other cost saving features. **Catalog 0106**

Rotary Actuators For Every Application

Parker has the broadest offering of rotary actuators available in industry. Both the rack and pinion and vane designs will provide long life in pneumatic or hydraulic service. The full range of actuators produce torques from six to 50,000,000 lb-in, with pressure ratings to 3000 PSI. Vane actuators are available in 28 standard sizes, rack and pinion actuators in 49 standard sizes, both with an unlimited selection of options allowing actuators to be customized to meet your application requirements. **Catalog 0106**

Pneumatic Automation Components For Increased Productivity

MotionMate 3D and Pneumatic Automation Components perform these basic functions — linear extension, vertical lift, base rotation, wrist rotation and gripping. These modules can be quickly combined to provide accurate robotic type movements. The unique internal construction eliminates the need for external guides, supports and slides; standard features include inductive sensors, flow controls, hydraulic shock absorbers, recirculating ball bearings and non-rotating rods. **Catalog 1830**

Servo Actuators And Systems

Parker features a full line of compact, integrated actuator/valve/electronics combinations in both linear and rotary configurations. They improve system response and simplify machine design by eliminating separate components and extra plumbing while providing one source responsibility. **Catalog 1455**

Flow Controls

Our "Colorflow" and "Partrol" lines include the industry's most complete selection of needle, gauge isolator, flow control and check valves. We also offer pilot operated checks, pressure controls, deceleration and high capacity two-way valves. **Catalog 3310 (Colorflow); Catalog 3350 (Partrol)**

Mobile Valves

Get custom design flexibility and proven reliability with our line of manually operated, solenoid operated or proportional D.C. solenoid models. All are available as individual valves or multiple valve sections. For those critical control applications, pressure compensated styles are also offered. **Catalog 2400**

Performance-Proven Piston, Vane and Gear Pump

Parker's broad range of energy-efficient lines include fixed and variable axial piston pumps with pressures to 5000 PSI. Mediu pressure variable piston pumps with speeds to 3000 rpm; pressures to 3300 PSI, with a wide range of control options and low noise operation. The variable vane pumps are stackable with pressure capabilities up to 2500 PSI. Vane and piston pumps are available with electrohydraulic servo pressure and flow controls complete with amplifier. Single and double gear pumps to 34 GPM and 3000 PSI plus an optional integral flow divider with built-in relief valve. **Catalog 2600-100-1/NA (Piston Pumps); Catalog 2600-200/NA (Vane Pumps); Catalog 2600-300/NA (Gear Pumps)**

Air Control Valves For Every Application

Every air system is unique... and Parker has the air valve you need. Parker air valves are available in spool, poppet or rotary disk design: 2, 3, and 4-way functions — 2- and 3-position, in sizes from 10-32 through $1\frac{1}{4}$ inch pipe ports NPTF, for pressure to 250 PSI. With solenoid, air pilot, manual and mechanical actuators. Mounting styles include inline, subbase, manifold, ar the new compact stacked manifold mounting. **Catalog 0107**

Systems and Service . . . Worldwide

Hydraulic Filters For Industrial And Mobile Applications

Maximize the built-in reliability of your hydraulic components with Parker Filtration products. Parker's complete filter line includes a wide range of models for pressure, return and suction filter applications. Other helpful products: Par-Gel™ water removal elements, Par-Fit™ competitive interchange elements, Par-Test™ fluid analysis services and portable filter carts. For trouble free service — specify Parker Filters! **Catalog 2300**

Air Preparation Units For Maintenance-Free Pneumatics

Protect your valuable pneumatic production equipment with Parker's complete line of top quality FRL units . . . Filters that remove water, rust and dirt . . . Unique solid-piston Regulators that resist rupture . . . Micro-Mist Lubricators that generate oil particles two microns or smaller for better lubrication . . . and Coalescent Filters with flows from 4 to 1000 SCFM. **Catalog 0700**

Parker Hydraulic Control Valves

Parker's broad line of hydraulic valves includes virtually everything from simple checks and flow controls to sophisticated closed loop servo systems. **Catalog 0108**

Electrohydraulic Valves — A variety of control capabilities and applications is possible with the broad selection of Parker electrohydraulic products which include proportional 4-way directionals, proportional throttles, electrohydraulic relief, proportional pressure reducing valves, servo valves and electronic controls. **Catalog 2550**

Directional Controls — include solenoid operated, pilot operated, manually operated and electrohydraulic proportional models. All valves conform to NFPA, ANSI and CETOP subplate mounting dimensions, with flows from 5 to 160 GPM (608 LPM). A full complement of Manapak sandwich valves is also available. They conveniently mount below the directional valve to provide check, flow, relief and pressure reducing functions.

Pressure Controls — include pressure reducing, relief, counterbalance, sequence and unloading valves. They are available in inline or manifold mounting styles in $^1/_4$", $^3/_8$", $^3/_4$" and 1$^1/_4$" sizes.

Cartridge Valves

Parker's broad line of threaded cartridge valves provide total system design flexibility, proven reliability and cost savings.

Threaded Style — Includes direct and pilot operated pressure controls, compensated and non-compensated flow controls, direct and pilot operated checks, manual and solenoid operated directionals, proportional flow and pressure reducing valves. They're available as cartridges, inline valves and custom designed integrated hydraulic circuit blocks. **Catalog 3100**

Insert Style — Parker also offers DIN insert type cartridge valves designed specifically for those high flow applications. They are capable of handling flows to 1850 GPM depending on the style. Insert cartridges are available as direct and pilot operated checks, electrohydraulic relief, proportional pressure reducing, proportional throttles and flow controls. These valves may be purchased as individual components or designed into complete custom designed manifold assemblies. **Catalog TK0200**

Power Units And Hydraulic Trainers

We produce everything in a Fluidpower system but the fluid. Parker's 50 plus years of Fluidpower experience includes designing and building systems with state of the art electrohydraulics . . . from Fixed and Variable Pump Vertical Power Units suitable for many applications; to complex systems for demanding, sophisticated applications such as aircraft and submarine simulators. The Parker Portable Hydraulic Trainer, utilizing industrial grade components, has been designed to be a tool for teaching hydraulic technology principles and circuitry. **Catalog 2600-500/NA**

In-Depth Fluidpower Training Programs

Practical, comprehensive courses in hydraulic and pneumatics for anyone involved with designing, specifying, and maintaining fluidpower equipment. The Parker-developed "Involvement Training" approach uses the latest teaching techniques, visual aids and student involvement to produce fast, easy comprehension. Courses cover everything from Basic Fluidpower to Advanced Hydraulic & Pneumatic Circuit Design . . . and courses are available for local presentation. **Catalog 0200-1**

For detailed product information . . . contact your local Parker Fluidpower distributor, the nearest Parker Regional Sales Office listed on the back, or call toll-free **1-800-272-7537**.

Parker Fluidpower

Circle 104

PARKER. The One Source you can depend on for total fluidpower Response-Ability WORLDWIDE.

PARKER FLUIDPOWER NORTH AMERICAN SALES OFFICES

Parker Hannifin Corporation
Fluidpower Group
Headquarters
17325 Euclid Ave.
Cleveland, OH 44112-1290
(216) 531-3000
Fax: (216) 486-6057

CALIFORNIA
16661 Noyes Avenue
Irvine, CA 92714
(714) 660-7033
Fax: (714) 852-9577

GEORGIA
2264 Northwest Parkway S.E.
Suite G
Marietta, GA 30067
(404) 956-0881
Fax: (404) 951-3017

ILLINOIS
500 S. Wolf Rd.
Des Plaines, IL 60016
(708) 298-2400
Fax: (708) 298-0533

MICHIGAN
651 Robbins Dr.
P.O. Box 3500
Troy, MI 48007-3500
(313) 589-2400
Fax: (313) 589-4769

NEW YORK
300 Marcus Blvd.
Smithtown, NY 11787
(516) 231-3737
Fax: (516) 434-1554

OHIO
17325 Euclid Ave.
Cleveland, OH 44112-1290
(216) 531-3000
Fax: (216) 486-6057
Telex: 980636

10683 McKinley Rd.
Cincinnati, OH 45242
(513) 793-2011
Fax: (513) 793-0853

TEXAS
1701 N. Collins Blvd., #139
Richardson, TX 75080
(214) 238-5020
Fax: (214) 669-8016

CANADA
Parker Hannifin (Canada) Ltd.
Fluidpower Group
530 Kipling Avenue
Toronto, Ontario M8Z 5E6
(416) 255-4567
Fax: (416) 251-6890

FLUIDPOWER CANADA-VANCOUVER
3054 Beta Avenue
Burnaby, B.C. V5G 4K4
(604) 299-8184
Fax: (604) 299-6631

MEXICO
Schrader-Bellows
Parker S.A. de C.V.
Calle 9 No. 6 Alce Blanco
053370 Naucalpan, Edo de Mexi
(905) 576-2411
Fax: (905) 358-1823

PARKER FLUIDPOWER INTERNATIONAL SALES OFFICES

AUSTRALIA
Parker Hannifin (Australia)
(Pty.) Ltd.
9 Carrington Road
Castle Hill, N.S.W., 2154
Australia
Tel: (61) (2) 634-7777

AUSTRIA
Fluidpower
Parker Hannifin NmF Buro Wien
Handelskai 52
A-1200 Vienna
Austria
Tel: (43) (222) 35 36 05/07

BRAZIL
Schrader Bellows
Industria a Comercia Ltda.
Sao Paulo
Tel: (55) (11) 263 2766

Parker Irlemp
Industria e Comercio Ltda.
Sao Paulo
Tel: (55) (11) 876-7988

DENMARK
Parker Hannifin Denmark A/S
Industribuen 8
DK. 2635 Ishoj
Denmark
Tel: (45) (2) 541133

ENGLAND
Parker Hannifin (U.K.) Ltd.
P.O. Box 170
6 Greycaine Road
Watford, WD2 4QA
Herts, England
Tel: (44) (923) (2) 44377

Parker Hannifin (U.K.) Ltd.
Peel Street
Morley, Leeds. Yorkshire
LS27 8EL
England
Tel: (44) (532) 537921

Pneumatic Division
Cannock
Tel: 543-462644

FINLAND
Oy Parker Hannifin (Finland)
Elimaenkatu 9
00510 Helsinki 51, Finland
Tel: (358) 878-4211

FRANCE
Parker Hannifin RAK, S.A.
B.P. 482-Ville-La-Grand
Zone Industrielled du Mont Blanc
74108 Annemasse, Cedex, France
Tel: (33) (50) 370294

GERMANY
Parker Hannifin N.M.F. GmbH
Geestemunder Strasse 42,
D-5 Koln 60, West Germany
Tel: (49) (221) 71720

Parker Hannifin NMF GmbH
Kaarst
Tel: 2101 5130

South Filderstadt
Tel: 7158 4035

Frankfurt
Tel: 69 319018

Hochmossingen
Tel: 7423 811162

Velbert (Pneumatics)
Tel: 2051 22077

HONG KONG
Parker Hannifin
Hong Kong, Limited
#2104 Hong Kong Worsted Mills
Industrial Bldg.
31-39 Wo Tong Tsui Street
Kwai Chung
Tel: (852) (0) 4288008

ITALY
Cylinder & Pneumatics
Parker Hannifin SpA
Via Carducci 23
21010 Arsago Seprio,
Varese, Italy
Tel: (39) (331) 768056

JAPAN
Parker Hannifin Japan, Ltd.
Mori Bldg. No. 11, 7th Floor
6-4, Toranomon 2-chome
Minato-ku. Tokyo 105
Japan
Tel: (81) (3) 504-3816

KOREA
Parker Hannifin Asia
Pacific Co., Ltd.
Korea Branch
1102 Dae Heung Bldg.
648-23 Yeoksam Dong
Kangnam-Ku, Seoul, Korea
Tel: (82) (2) 568-3201/2

LATIN AMERICA
1740 NW 96th Avenue
Miami, Florida 33172
Tel: (305) 594-0748

THE NETHERLANDS
Parker Hannifin N.V.
Edisonstraat 1,
7570 At Oldenzaal
The Netherlands
Tel: (31) (5410) 85000

NEW ZEALAND
Parker Hannifin (N.Z.) Ltd.
Cnr. Kerwin Avenue & Lorien Pla
P.O. Box 58233
East Tamaki
Auckland, New Zealand
Tel: (64) (9) 274-4095

NORWAY
Parker Hannifin A/S
Handsverkvegen 4
Postboks 8
N-1408 Vevelstad, Norway
Tel: (47) (2) 867760

SINGAPORE
Parker Hannifin Singapore Pte. L
No. 11-4th Chin Bee Road
Jurong Town
Singapore 2261
Tel: (65) 261-5233

REPUBLIC OF SOUTH AFRIC
Parker Hannifin (Africa) (Pty.) Ltd
42 Steel Road
P.O. Box 1153
Spartan, Kempton Park
Transvaal 1620
Republic of South Africa
Tel: (27) (11) 970-3630

SPAIN
Parker Hannifin Espana S.A.
Ebro 18, Torrejon de Ardoz
Madrid, Spain
Tel: (34) (1) 675-7300

SWEDEN
Parker Hannifin (Sweden) AB
Siktgatan 11
S-162 26 Vallingby, Sweden

PARKER FLUIDPOWER DISTRIBUTORS

Parker Fluidpower components are available off-the-shelf from over 70 stocking distributors coast-to-coast. These same distributors are also staffed with factory-trained fluidpower specialists to provide expert engineering assistance and technical help for all of your fluidpower requirements.

Fluidpower Group
Parker Hannifin Corporation
17325 Euclid Avenue
Cleveland, OH 44112
216/531-3000

Bulletin 0101.B1
©1990 Parker Hannifin Corporation
Printed in U.S.A.

Parke
Fluidpowe

Circle 104

crement of time. A pulse count from a position-measuring transducer indicating drive position is then subtracted from the commanded position. The pulses from the transducer are considered negative feedback. Thus, subtracting the position information yields the difference between drive position and the position command. The total position difference is often called the following or static error.

The error is sent to a digital-to-analog (d/a) converter for conversion to an analog voltage that is proportional to the position difference. Drive voltage then generates motion in a motor, creating a new position which attempts to reduce the following error.

The more widely used incremental transducers generate pulses corresponding to position and direction of motion. Each time the transducer moves a distance corresponding to one pulse (forward or reverse), a counter increments or decrements by one. After a series of moves, the counter contains a sum of pulses corresponding to position.

The controller, d/a converter, and position feedback are commonly called the position loop. Position-loop calculations are generally handled by a microprocessor or computer.

In the velocity loop, the voltage from the d/a converter is combined with voltage produced by a tachometer attached to the positioning motor. The tachometer voltage indicates motor speed and is also negative feedback. Subtracting the tach feedback from the d/a converter voltage yields a voltage proportional to the difference between actual and commanded velocity. An amplified error voltage drives the positioning motor directly. The d/a converter output, amplifier, and motor/tach are called the velocity loop.

To understand how the basic closed-loop system functions, consider a case where the controller commands the system to move ten increments, and each increment represents 0.001 in. The number in the accumulator increases instantly to 1,000 counts. This produces a voltage output from the d/a converter which is interpreted as a velocity command by the motor.

The motor then starts to move, causing the encoder to send out a pulse for every increment of motor shaft rotation. Each of these pulses produces a subtraction from the number in the accumulator. Thus, the following error in the accumulator represents the difference between commanded and actual position. As the motor moves, the following error decreases.

As more position commands are sent, the system accelerates and approaches the commanded position. With each iteration of commands, the number in the accumulator increases and the system moves faster than in the preceding iteration. Eventually, the number subtracted from the accumulator is the same as the number added. The velocity then stops increasing, and the following error reaches a steady-state value that becomes the following error for the system at a specific velocity.

MOUNTING PRECISION EQUIPMENT

For machine tools, heavy steel and cast-iron bases offer sufficient mass and stability for precision work. However, in the micron and submicron range, other materials, such as honeycomb constructions and granite have advantages in that they are more rigid than cast iron, steel, or aluminum.

In addition, granite has a high thermal inertia that makes it less susceptible to temperature changes. Granite is also easily cut to shape and can be lapped and polished to optical tolerances. This makes granite preferable where flatness is critical. Other advantages of the stone is that it is immune to many chemical agents, is nonmagnetic, and does not conduct current.

Optical-quality work tables of honeycomb are used because of their high strength-to-weight ratio. However, table characteristics vary among manufacturers because of differences in core and skin materials, cores size and, to a lesser extent, the internal damping materials used.

Positioning components

A number of positioning components are commonly employed in industrial closed-loop systems today. These components fit the general categories of controllers, mechanical positioning hardware, feedback transducers, and motors.

Outputs from closed-loop positioning systems are rotary or linear motion. At power levels under 100 hp, dc motors are generally used. However, stepping motors are sometimes operated in closed-loop mode, though they are torque limited and generally are available only up to sizes corresponding to about 3 hp. Thus, stepping motors cannot accelerate as rapidly or run as fast as some servomotors.

In addition, there is also high interest in powering ac induction motors in closed-loop mode. When used with the proper controller, induction motors can provide dynamic response equal to or better than that of brushless dc drives for applications above about 10 hp. However, the design of drives for these motors tends to be more complicated than for dc, often making this approach more expensive.

Many types of position transducers can be used. Common transducers include lasers, potentiometers, optical encoders, resolvers, and magnetic scales. Transducers can be functionally divided into absolute and incremental types. Incremental encoders typically generate a pulse for every increment of motion over which they travel. To gage position, a controller counts the pulses. The most common incremental encoders are rotary optical encoders, linear optical encoders, and linear magnetic encoders. Other types also used (particularly for high resolution) include resolvers, synchros, and devices called Inductosyns.

Absolute transducers give a direct indication of position, but are normally quite costly. They typically gage position by generating a discrete code for every increment of motion over which they travel. A controller then uses a translation table in memory to relate the code read from the transducer into system position. Absolute encoders are available in both rotary and linear optical types.

Tachometers are probably the most widely used velocity transducer. In addition, velocity transducers are sometimes designed with Hall-effect sensors for special applications. Finally, some systems differentiate the position feedback signal to compute velocity. Thus, a velocity transducer is not needed.

Positioning hardware and mechanical coupling in both closed-loop and open-loop systems can take a variety of forms. Older motion-control systems generally used either belt or gear couplings between the driven shaft and the motor. But modern systems now often make the drive motor and feedback encoder an integral part of the driven shaft to avoid backlash and other instabilities.

Typical positioning mechanisms include ball screws, lead screws, planetary roller screws, and simple ball/nut mechanisms. Most systems that provide linear motion or translate rotary motion into linear motion incorporate these components. A typical example is x-y table movement.

In addition, devices called linear actuators combine ball screws with other actuation components such as slip clutches and feedback control. Special positioning mechanisms such as voice coils are used in applications demanding fast response. The typical use for such hardware is high-speed hard-disk drives.

For positioning extremely heavy loads, hydraulic actuators are sometimes used. These devices, referred to as electric cylinder jacks, can move about 20 tons and may be supplied with integral positioning or speed controls.

HIGH-PRECISION POSITIONING

Ball screws on machine tools routinely position heavy workpieces (a few hundred pounds) to within 0.001 in. But positioning requirements for lighter loads, such as in printed-circuit manufacturing, medical equipment, and some industrial-inspection devices, have pushed the need for precision positioning to the micrometer level. For these tasks, machines are usually equipped with micropositioning slides and rotary tables.

Micropositioning slides position workpieces or tools to 0.0001-in. accuracy or better and with similar repeatability. In these units, the mechanism that positions a slide table is often a ground lead screw carrying a preloaded nut. The nut is coupled to the table through a device that transmits axial loads but not moment loads. This is necessary to avoid inducing any distortion or moment loads that may affect accuracy.

While micropositioning slides often carry only a few pounds (loads in excess of 100 lb are also possible), they must have repeatable performance to 10^{-6} m. For this, loads are usually carried on a ball bearing or crossed-roller slides with races made of opposing V-grooves. This arrangement allows the slide to carry normal, side, and moment loads, and permits mounting the slide vertically as well as horizontally.

In extreme-precision equipment, the lead screw and nut are matched with tight fits and may introduce some thermal expansion from heat generated by friction in the nut. To avoid a thermal expansion error, a capstan drive can be substituted. Sensitivity of a positioning table that uses a capstan drive can approach 0.01 microns (0.01×10^{-6} m).

For positioning tasks that require motion in several axes, manufacturers can assemble a number of off-the-shelf rotary tables and slides. Some complex units combine tables for x, y, and z-motion and rotation about each axis. This provides 6-axis positioning.

Controls

Measuring a tool or sample position was formerly done by reading a micrometer dial. In fact, many micropositioning slides are equipped this way, but their travel length is limited to a few inches. Newer devices control positioning with programmable logic controllers (PLCs) or PCs.

For repetitive tasks, as in manufacturing or inspection, PLCs and PCs are preferred. An additional advantage of PCs is that a multiaxis positioning unit, using stepping motor-powered micropositioning slides, is relatively easy to program with the right software or command set.

For example, to drive a stepping motor, the command 1 PR +3,000 signals axis 1 to position its table 3,000 steps relative to where it is now. The additional command 1 VA 2,000 signals the same motor to turn at an absolute velocity of 2,000 steps/s. Defaults for acceleration and deceleration control those parameters if no commands are given for them.

In addition to counting steps, linear potentiometers and optical devices can be installed for positioning with better than 0.0001-in. precision. In fact, before shipment, some manufacturers check the accuracy of their units with interferometers that are capable of measuring position to within a few wavelengths of light. Tables or slides are shipped with records to show the accuracy of the unit. Furthermore, these records are useful in troubleshooting or maintenance because they provide a baseline to which equipment performance can be returned.

There are both hydraulic and pneumatic actuators with built-in positioning controls as well. Hydraulic valves are available with embedded closed-loop controls. These devices are used to provide proportional control of valve position. They are also commonly embedded into linear and rotary hydraulic actuators to provide closed-loop actuator systems. Typical applications are those where loads on the order of hundreds of pounds or more must be positioned to accuracies of a few tenths of an inch. Flight simulators, for example, use these devices.

In addition, closed-loop systems comprising a pneumatic cylinder, controller, and linear position sensor are available. These devices generally handle loads of a few pounds and provide better accuracy, on the order of 0.001 to 0.0001 in. They are often alternatives to mechanical positioning equipment such as ball screw-based systems.

The controllers range from single-chip microcontrollers to full-blown industrial computers. The approach used depends on such factors as positioning speed and response to changes in external loading.

Loop variations

Simple closed-loop control has been used for decades to perform machine tool contouring. But a number of refinements are increasingly found in industry today. These refinements are usually aimed at handling special control applications that may include synchronization of multiple axes or web presses. Additional improvements handle high-speed precision positioning and changing loads and inertias when positioning the joints in robot arms.

Common variations on the basic closed-loop techniques often concern four specific areas: filtering, synchronization of multiple axes, handling instabilities caused by gear backlash, and obtaining low position error during acceleration and deceleration.

Filtering

The design of a closed-loop positioning system demands that special trade-offs be made in loop gain and bandwidth to ensure stability. Otherwise, the system may oscillate during a move or exhibit other behavior that degrades positioning accuracy. One way of providing the needed stability is by adding special filtering in the position loop.

Filtering is also used to reduce following error to essentially zero in certain systems. The usual technique is to

SIEMENS

Taking orders today, for the year 2000... and beyond.

Commitment.
Siemens is committed to taking your order now, or any time, until the year 2000 and beyond.* And we'll deliver it now or then to suit your schedule.

This offer covers the SIMATIC® TI305™, TI405™ and TI505™ PLCs, TISTAR™ and APT™ software, SIMATIC S5 PLCs and SICOMP® industrial PCs. Siemens has been making significant research and development investments into each of these product lines and will be offering them on a continuous improvement basis. But that is to be expected from Siemens.

We are the world's largest PLC company.

For generations people throughout the world have been able to depend on Siemens in the areas of electrical and electronic technology. Our products and experience span the needs of many industries with service and support in over 120 countries. Without the strength size brings, profitable operations in the global market are no longer possible.

*Special Terms and Conditions Apply

One global supplier, many solutions.

The needs of people throughout the world are steadily converging. Products and services today are developed and produced for the entire world. Today Siemens spends more in automation research and development than most PLC companies make in sales. As a global technology leader we have an optimal solution for your specific needs. For more information concerning the benefits of switching to Siemens programmable controllers, complete the enclosed reader response card or call Siemens Industrial Automation Inc., 1-800-964-4114.

Siemens Industrial Automation, Inc.
The Power of Global Automation

©1992 Siemens Industrial Automation, Inc. Siemens, SIMATIC and SICOMP are registered trademarks of Siemens AG. TISTAR and APT are trademarks of Siemens Industrial Automation, Inc. TI305, TI405 and TI505 are trademarks of Texas Instruments Incorporated

Circle 105

SIEMENS

That was then.

GE® Fanuc Series One.™

Had trouble ordering a GE Fanuc Series One recently? If so, the SIMATIC TI305™ PLC uses identical hardware and offers more benefits.

The SIMATIC TI305 PLC is a one to one replacement for the Series One PLC. Every module, base, CPU and software package designed for the Series One PLC will work with the SIMATIC TI305 PLC. Converting to the SIMATIC TI305 PLC means that you can leverage all your programs, training, documentation and engineering time.

Siemens' investment in the SIMATIC TI305 platform will give your machines years of competitive advantages.

Soon Siemens will be offering the new SIMATIC TI335™ CPU for the SIMATIC TI305 PLC family. The advanced semiconductor technology applied to this new CPU allows it to execute a 1K program in under 1 millisecond, provide built-in communications and offer an intelligent bus for future I/O development. This technology makes the SIMATIC TI305 platform the hottest performer in its class at one of the lowest prices. Best of all, this new, high tech, best value CPU is compatible with all installed GE Fanuc Series One PLC products.

The SIMATIC TI305 PLC is backed by the world's largest PLC company . . .Siemens.

Siemens is the world's largest supplier of PLCs. As a global supplier, Siemens backs its commitment to the automation market with investments of approximately $1M a day on research and development.

This is now.

SIMATIC® TI305.™

Investments of this scope are more than the sales of most PLC companies; that's a lot of commitment and a lot of advantages for you.

Don't switch to less advantaged PLCs. The enhanced SIMATIC TI305 PLC is available for delivery today and for years to come.

The SIMATIC TI305 PLC of today offers advantages not found on the GE Fanuc Series One PLC. The SIMATIC TI305 PLC offers more base sizes, new modules, RS-232 communications, structured programming, a great networking package, one of the easiest to use programming packages, product line agency approvals including UL, CSA and FM Class 1 DIV2. and lower prices on many popular devices. And with Siemens, the world's largest PLC manufacturer in the world, you will find support in over 120 countries throughout the world.

For more information concerning the benefits of switching to the SIMATIC TI305 PLC, complete the enclosed reader response card or call Siemens Industrial Automation Inc., 1-800-964-4114.

Siemens Industrial
Automation, Inc.
The Power of
Global Automation

©1992 Siemens Industrial Automation, Inc. SIMATIC is a registered trademark of Siemens AG. TI305 and TI335 are trademarks of Texas Instruments Incorporated. GE and Fanuc Series One are trademarks of General Electric Corporation

Circle 105

anticipate a certain amount of following error by integrating. Integration effectively causes the processor to command a higher velocity than it would normally, thus reducing the amount of position error.

This integration is applied to the position feedback from the encoder. Differentiation filtering is also used. This generally compensates for the mechanical time constant of a motor by incrementing or decrementing the position feedback depending on how fast it changes. Also, feedback is multiplied by a constant or proportional term that is basically a gain.

The three actions — proportional, integral, and differential (PID) — can be thought of as implementing a band-pass characteristic in the position feedback loop. By changing constants associated with each of the three operations, the system can be tuned for stability under different loads and position resolutions.

Some systems implement only the PD part of PID functions. This is called phase-lead filtering because it introduces positive phase over some frequency band. The effect is that of a high-pass filter.

Backlash instability

A technique called dual-loop control is sometimes used to compensate for instabilities caused by backlash. Backlash arises in systems where a motor is coupled to a load through gears or lead screws. When a position encoder is installed on such loads, a sufficient level of backlash can make the feedback oscillate. This phenomenon can be a limiting factor for precise movements.

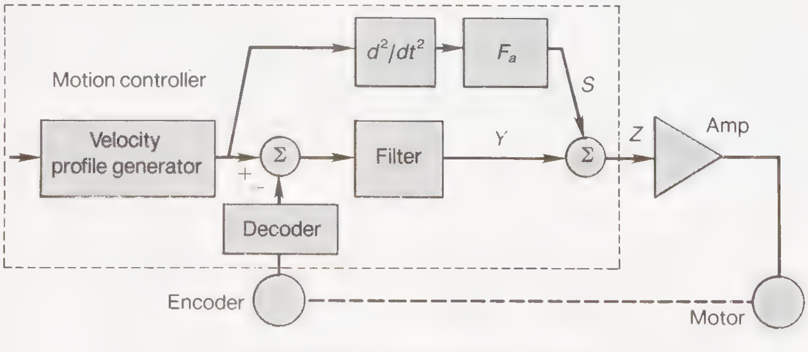
Dual-loop control uses two feedback encoders, one on the motor, the other attached to the load. The motor encoder closes one loop that provides motor control. The load encoder closes a second supervisory loop that monitors load-position errors and then commands the motor-control loop to move.

A dual-loop algorithm would first command the motor to move a certain interval at a specified speed. Once this move is complete, the program would check the position of the load encoder to determine if any position error remained, then command the motor to move until error hit zero.

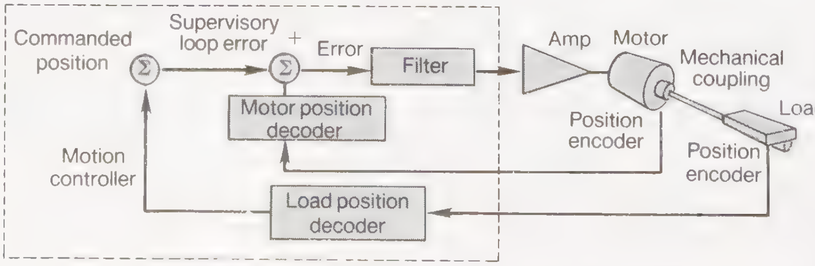
Another use for this algorithm is where a clutch couples the motor to a load. Dual-loop control can provide smooth motion through motor velocity and load-position profiles. For example, say that the motor must accelerate to some constant velocity, hold this velocity for a time, then decelerate to a stop. With no slippage, the load position is simply the integral of the motor velocity profile. One approach to the algorithm is to give the motor a command to reduce velocity when the load position is a certain number of counts from its final destination. When the load is a few counts closer to the end, the motor is commanded to stop.

The solution is independent of slip because it makes the motor run longer to make up for the slip in rotation. Of course, the motion profile could contain a number of set points and velocity changes for more complex profiles.

FEEDFORWARD BLOCK DIAGRAM



BASIC DUAL LOOP CONFIGURATION



Adaptive control

Another class of control techniques, collectively referred to as adaptive control, is starting to be used in industry. Although the basic algorithms have been known for decades, they have seldom been applied in real applications because they are calculation-intensive. However, the advent of special-purpose digital signal processor (DSP) chips has brought renewed interest in adaptive-control techniques. The reason is that DSP chips contain hardware that can implement adaptive algorithms directly, thus speeding up calculations.

The main purpose of adaptive-control techniques is to handle situations where parameters such as loads, inertias, and other forces acting on the system change drastically.

A classic example of a system with changing parameters is a guided missile. Missile mass drops as fuel burns, and it encounters differing friction at different altitudes.

Some system changes can be unpredictable, and ordinary closed-loop systems may not respond properly when the system transfer function varies. Sometimes, these effects can be handled by conventional linear-control techniques such as gain scheduling (feed-forward control). Conservative design practices may also enable some systems to remain stable even when subjected to parameter changes or unanticipated disturbances.

The price paid for such stability is suboptimal performance, however. Response to changes may be sluggish. Errors may fail to stay within satisfactory limits, or designs must compensate for loose error tolerances in other ways.

Adaptive control can help deliver both stability and good response. The approach changes the control algorithm coefficients in real time to compensate for variations in the environment or in the system itself. In general, the controller periodically monitors the system transfer function and then modifies the control algorithm. It does so by simultaneously learning about the process while controlling its behavior. The goal is to make the controller robust to a point where the performance of the complete system is as insensitive as possible to modeling errors and to changes in the environment.

Even ordinary feedback-control systems are adaptive in a limited sense, in

Compumotor
Daedal
Digiplan

Positioning Systems and Controls

Parker

Daedal

Innovative Solutions for Programmable Position Control

A Broad Range of Capabilities

If you have a motion control problem, turn to Compumotor, Daedal and Digiplan. We offer a comprehensive lineup of product technologies, plus we provide the technical support to ensure timely, expert assistance in product selection, installation, programming, training and trouble shooting. From hands-on technical seminars to local Automation Technology Centers to factory-trained field application engineers, solutions to your motion control problem are only a phone call away.

A Basis to Objectively Recommend the Best Solution

A full spectrum of motion control technologies allows us to objectively recommend the best solution to your specific problem. We offer:

- Half/full step and microstepping systems
- Digital and analog drives
- Open loop and closed loop systems
- Brushed and brushless motor/drives
- Position, velocity and torque control servos
- Stand-alone and peripheral controls
- Absolute and incremental feedback
- X-Y linear and rotary tables
- Positioning stages and slides
- Custom tables with payloads to 7,700 pounds and travels to 10 feet
- Direct drive rotary motors and motors attached to gearboxes, tables, etc.
- Linear motors and motors mounted to leadscrews, belt drives, etc.

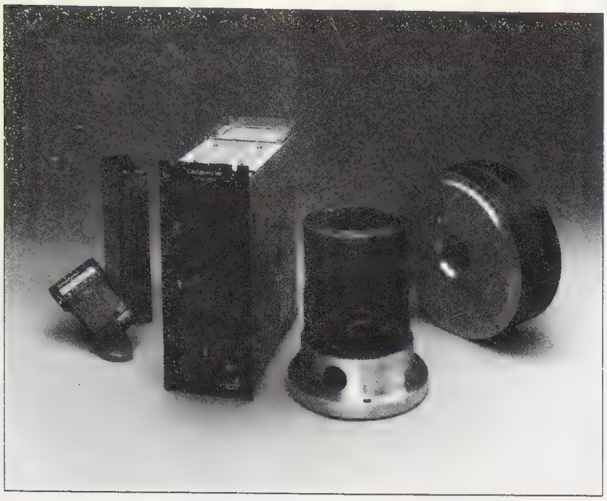
So, if you're looking for the final word on motion control, turn to the companies that have all the possibilities—Compumotor, Daedal and Digiplan.

Parker

Circle 109

Direct Drive Servo Systems

Compumotor



Dynaserv Series

Features	DM Series	DR Series	DR5000 Series
Max continuous torque (lb-in)	1239	2478	3098
Max peak torque (lb-in)	1770	3540	4426
Max speed (rpm)	120	120	240
Number of axes	1	1	1
Mounting type	Rack or Panel	Rack or Panel	Rack or Panel
Feedback type	Encoder	Resolver	Resolver
Step and direction control	•	•	•
Analog control	±10V	±10V	±10V
Control loop	Velocity, Torque, Position	Velocity, Torque, Position	Velocity, Torque, Position
Resolution (steps/rev)	655,360 or 1,024,000	507,904 or 819,200	278,528 or 425,984
PWM switching frequency	11 kHz	11 kHz	11 kHz
Power input	115 or 230VAC	115 or 230VAC	200 or 230VAC
Short circuit, over temperature and brownout protected	•	•	•
LED diagnostics	•	•	•

Compumotor Division
5500 Business Park Drive
Rohnert Park, CA 94928
800-358-9070

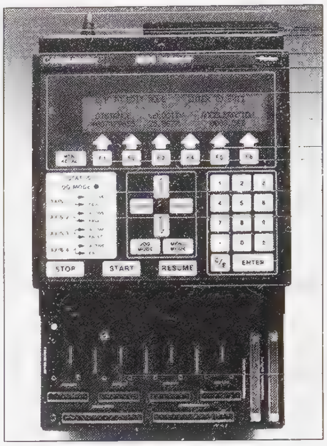
Parker

Circle 109

Microprocessor-

MC20 – 2-axes indexer

Model 500FOL – indexer/follower



Model 4000 – 4-axes indexer

Model	Operates stand alone	PLC compatible	Computer compatible	Number of axes	Non-volatile memory	Maximum step output (kHz)	User-selectable inputs/outputs	Go Home function	Jog function	Control panel and display
IFX	•	BCD or RS-232C	RS-232C	1	EEPROM	640	3/2	•	•	
MC20	•	• (Digital I/O)		2	BBRAM	800	2/2	•	•	•
2100	•	RS-232C	RS-232C or IEEE-488	1		1,000	3/1	OPT		
300 Series		TI Series 305® & GE.Fanuc Series 1*		1-3		325	5/8	•		
500 Series	•	BCD or RS-232C	RS-232C	1	BBRAM	1,000	13/8	•	•	RP240
4000	•	BCD or RS-232C	RS-232C or IEEE-488	1-4	BBRAM	500	28/28	•	•	•
PC21			IBM® PC Bus	1		500	3/1	•		
PC23			IBM® PC Bus	1-3		500	6/6	•	•	
AT6400		BCD	IBM®PC/AT Bus	1-4		1,600	28/24	•	•	
6200	•	BCD or RS-232C	RS-232C	1-2	BBRAM	1,600	26/26	•	•	RP240

Accessories

RP240 Remote Panel Operator Interface

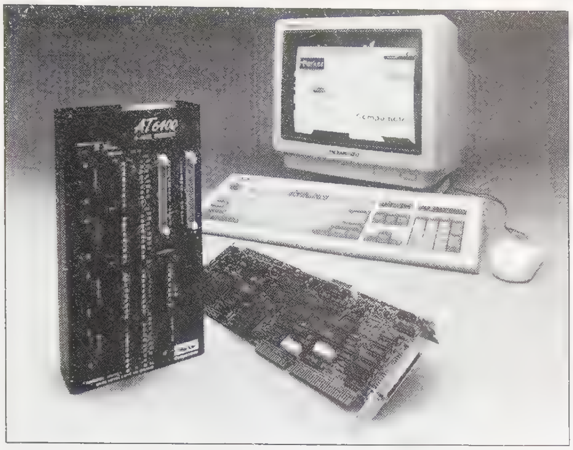
- Directly compatible with Compumotor's SX Series and ZX Series indexer/drives, and the 500 and 6200 indexers
- Interfaces with any controller capable of transmitting ASCII strings across RS-232C (three-wire screw-terminal interface)
- Two-line, 40-character per line LCD display with adjustable contrast
- Sealed membrane keypad meets NEMA 12 specifications
- Requires only 5 VDC (at 100 mA) to operate—can be supplied by the SX, ZX, 500 or 6200

TM8 Thumbwheel Operator Interface

- Directly compatible with Compumotor's SX Series and ZX Series indexer/drives, 500 Series, AT6400 and 6200 indexers.
- Eight digits can be used for velocity, distance, number of loops, following ratio, sequence execution, etc. (e.g., two for acceleration, three for velocity and three for loop count)
- Suitable for panel mounting

Circle 109

based Indexers


AT6400 – 4-axes IBM PC® compatible indexer

6200 – 2-axes stand-alone indexer

Thumbwheel interface	Joystick interface	Incremental encoder interface	Absolute encoder interface	Distance scaling-to-user units	Teach mode	Velocity profiling	Circular interpolation	Linear interpolation	Math functions	Encoder following
		•				•				
				•						
		OPT		•		•				
		301 only				•				
TM8		•	•	•		•			•	FOL version
•	•	•	•	•	•	•	OPT	•	•	OPT
		•				•				
	•	•				•	OPT	OPT		
TM8	•	•		•		•	•	•	•	
TM8	•	•		•			OPT	•	•	

AL-C and AR-C Absolute Encoders

Common features

- Microprocessor-based decoder box (with integral power supply) interfaces directly with Compumotor's SX Series indexer/drive, 500 Series and 4000 indexers.
- Absolute position retained in the event of power outage

AL-C (Absolute Linear Encoder)

- User-selectable resolutions of 4096, 8192, 16384 and 32768 positions per inch
- 12 standard lengths from 8 to 144 inches
- Accuracy: ±0.001 inch; repeatability: ±0.0001 inch

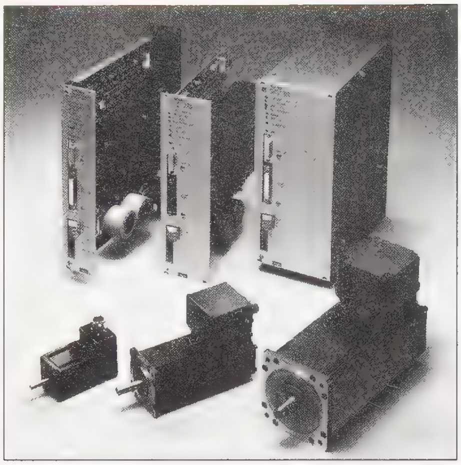
AR-C (Absolute Rotary Encoder)

- User-selectable resolutions of 2048, 4096, 8192 and 16384 positions per revolution
- Range: 512 revolutions of absolute positioning
- Accuracy: ±0.0002 rev; Repeatability: ±0.000061 rev

Compumotor Division
5500 Business Park Drive
Rohnert Park, CA 94928
800-358-9070

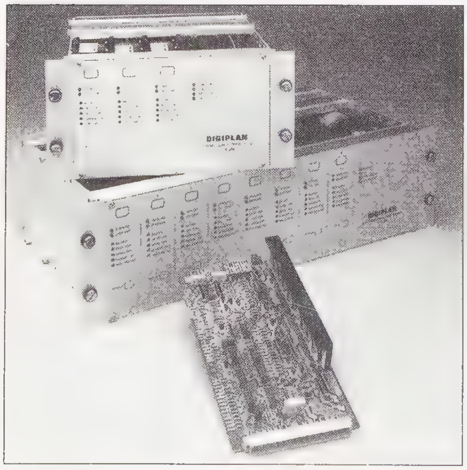
Circle 109

AC Brushless and DC

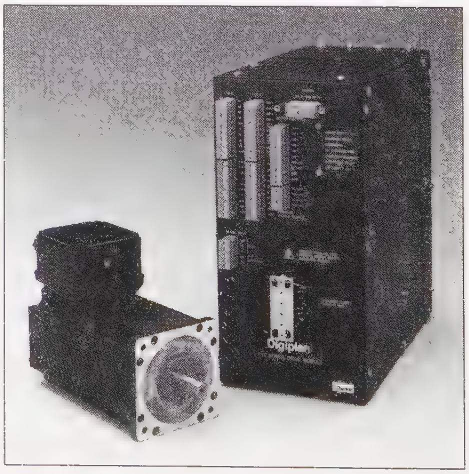

BL Series

Compumotor Plus

	Series	Max Continuous/ Torque (lb-in)	Max Peak torque (lb-in)	Max speed (rpm)	Number of axes	Mounting type	Feedback type	Step and Direction control	Analog control	Control loop
Brushless Servo Systems	BL	35.0	115.0	12000	1	Rack or Panel	Encoder		±10V	Velocity Torque
	BLX	35.0	115.0	12000	1	Rack or Panel	Encoder	●		Velocity, Torque Position
	Compumotor Plus	68.75	68.75	3000	1	Panel	Resolver	●		Position
	PS7	18.75	62.5	7500	1	Panel	Encoder	●		Position
	System 7 AC Brushless	35.0	59.0	7500	1-3	Rack	Encoder	●		Position
	System 7 Hybrid	40.2	40.2	3000	1-3	Rack	Encoder	●		Position
	Z	562.5	1125.0	7000	1	Panel	Resolver	●	±10V	Velocity, Torque Position
Brushed Servo Systems	UD2/ UD5	4.0/14.0	11.0/26.0	5000	1-8	Rack or Panel	Encoder (Tach optional)		±10V	Velocity Torque
	UD12	50.0	115.0	2500	1-8	Rack or Panel	Encoder (Tach optional)		±10V	Velocity Torque



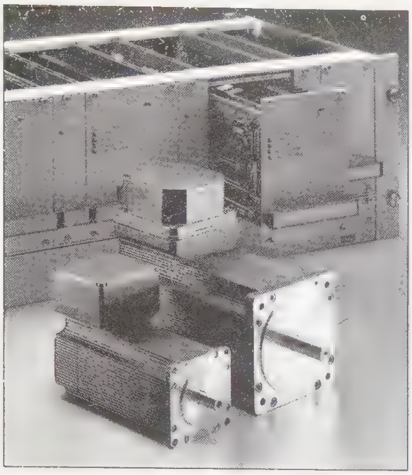
UD Series



PS7 Series

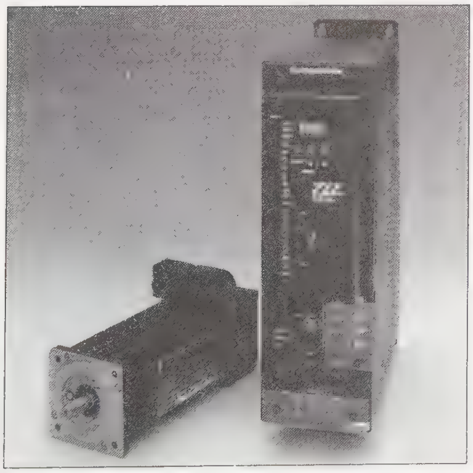
Circle 109

Brushed Servo Systems



System 7

Resolution (steps/rev)	PWM switching frequency	Power input	Short circuit, over temp. & brownout protected	Digital tuning	LED diagnostics	RS-232C diagnostics	Indexer					End-of-travel limits
							RS-232C compatible indexer in drive	Programmable sequences	Programmable inputs/ outputs	Encoder following		
2000 4000	20KHz	61-107VAC	•		•							
2000 4000	20KHz	61-107VAC	•	•	•	•	•	63	12/3	•		•
200 to 25600	18KHz	36 or 120VAC	•	•	•	•	CPX	40	3/2			CPX
2000 4000	20KHz	120VAC	•	•	•	•	PS7X	63	12/3	•		PS7X
2000 4000	20KHz	107VAC	•	•	•	•	Control Card	63	12/3	•		Control Card
2000 4000	20KHz	107VAC	•	•	•	•	Control Card	63	12/3	•		Control Card
200 to 65536	7KHz	120-240VAC	•	•	•	•	ZX ZXF	100	7/4	ZXF		ZX ZXF
Encoder Dependent	20KHz	24-85VDC (120VAC)	•		•							•
Encoder Dependent	20KHz	24-85VDC (120VAC)	•		•							•



Z Series

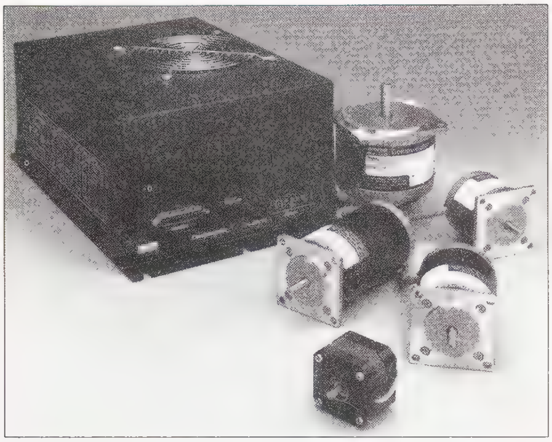
Accessories	Compatible Products
TM8 Thumbwheel Module*	ZX, ZXF
RP240 Remote Panel interface*	ZX, ZXF

Compumotor Division
5500 Business Park Drive
Rohnert Park, CA 94928
800-358-9070

Circle 109

Compumotor

Packaged & Rack Mount

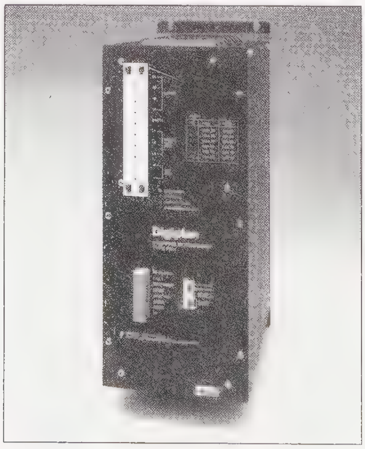


LN Series

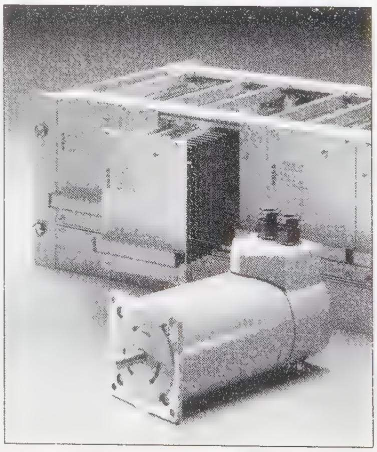
S Series

	Series	Torque range (oz-in)	Max speed (rpm)	Maximum current per phase (amp)	Drive type	User-selectable Resolutions (steps/rev)	Power input	Minimum motor inductance (mH)	Motors available (frame sizes)	User-selectable current range
Full/half stepping systems	PK2	40–150	1800	2.0	Bipolar Chopper	200 400	120 or 240VAC	1.0	23, 34	●
	PK3	40–250	1800	3.0	Bipolar Chopper	200 400	120 or 240VAC	1.0	23, 34	●
	PK130	960–5000	3000	18.0	Bipolar Chopper	200, 400 1000, 2000	120 or 172VAC	0.75	42, 64	●
Microstepping systems	S	65–1900	3000	8.0	Bipolar PWM	200 to 50800	120VAC	0.5	23, 34, 42	●
	OEM 650	35–390	3000	7.5	Bipolar PWM	200 to 50800	24–75VDC	0.5	23, 34	●
	L (Linear)	20 lbf	75 ips	3.0	Bipolar PWM	5000 to 12500 steps/in	120VAC	5.0	L20	●
	LN	14–150	1800	2.2	Bipolar Linear	200 to 101600	120 or 240VAC	0.5	17, 23, 34	●
Rack mount systems	SC	40–250	1800	4.5	Bipolar Chopper	200 400	120, 240 or 440VAC	1.0	23, 34	●
	CC	40–1500	3000	8.0	Bipolar Chopper	200, 400 1000, 2000	120, 240 or, 440VAC	0.5	23, 34, 42	●
	HR full/half/mini	565–3825	3000	18.0	Bipolar Chopper	200, 400 1000, 2000	120, 240 or 440VAC	0.75 1.50	42, 64	●
	System 7 microstepping	100–440	3000	5.0	Bipolar PWM	400 to 12800	120, 240 or 440VAC	0.5	34	●

SC, CC & HR Rack mount systems



PK130

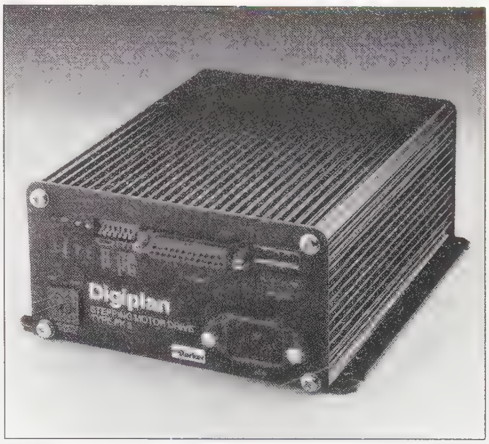


System 7

Circle 109

Step Motor Systems

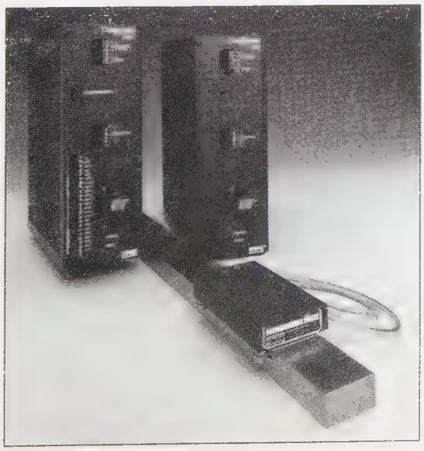
OEM Series



PK3

Programmable wave form for optimum smoothness	Standby current reduction	Step and direction input	Optically isolated inputs	Over temp., short circuit phase to phase protection	Brownout protection	Indexer included in drive or rack	RS-232C interface	Programmable sequences	Inputs/ outputs	Encoder interface	Encoder following
	•	•		short circuit only							
	•	•	•	•							
•	•	•	•	•	•						
•	•	•	•	•	•	SX SXF	•	100	4/8	Absolute Incremental	SXF
•	•	•		•	•	OEM650X	•	7	3/2	Incremental Option	
•	•	•	•	•	•	LX	•	40	6/2		
•	•	•	•	•	•						
		•	•	•		IFX or MC20	IFX	7	3/2	Incremental	
•	•	•	•	•	•	IFX or MC20	IFX	7	3/2	Incremental	
•	•	•	•	•	•	IFX		7	3/2	Incremental	
•	•	•	•	•	•	RS-232 Module	RS-232 Module	63	12/3		

Indexer

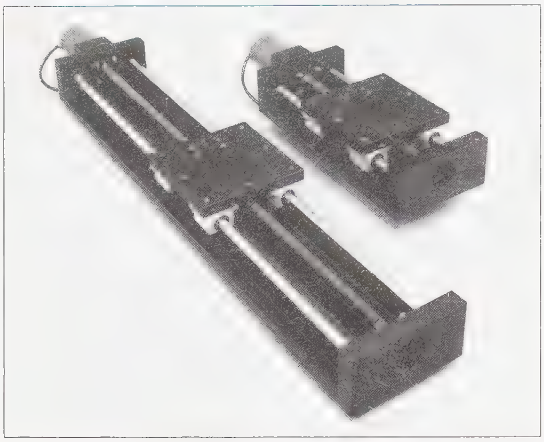


LX Series

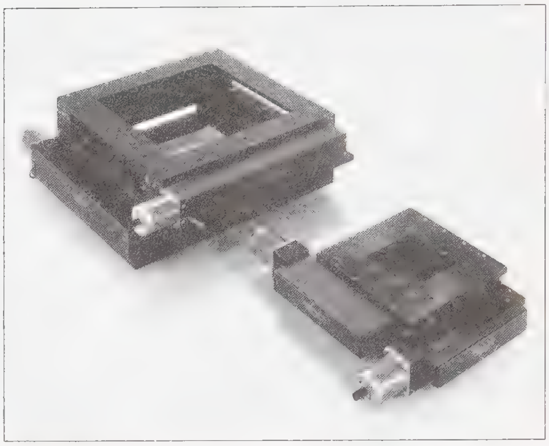
Accessories	Compatible Products
TM8 Thumbwheel Module*	SX, SXF
RP240 Remote Panel interface*	SX, SXF
AR–C Absolute Rotary Encoder*	SX, SXF
AL–C Absolute Linear Encoder*	SX, SXF

Compumotor Division
5500 Business Park Drive
Rohnert Park, CA 94928
800-358-9070

Motorized



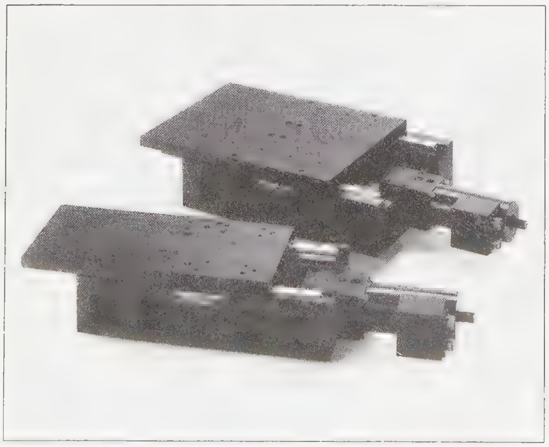
Rail



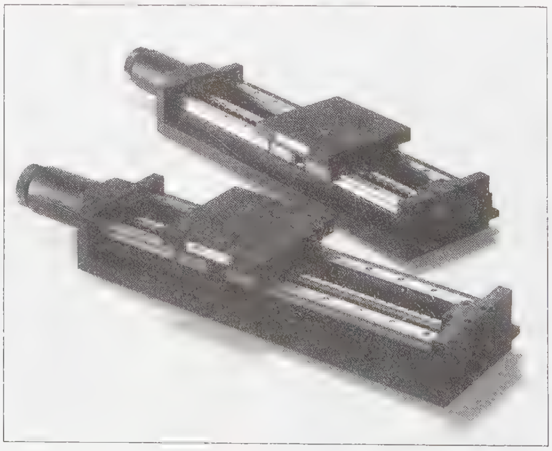
Open frame

	Linear Ball Bearing			Cross Roller				Square Rail
Table	**100000 Series**		**200000 Series**	**600000 Series**	**700000 Series**	**800000 Series**		**400000 Series**
Grade	**Standard**	**Precision**	**Standard**	**Precision**	**Precision**	**Standard**	**Precision**	**Precision**
Travel – inches	24	24	24	18	18	12	12	60
Load Capacity[1] Horizontal – lb	300	300	380	900	1000	300	300	2340
Speed[1] – in/sec	3	3	3	11	11	16	16	16
Ground Lead Screw	Standard	Standard	Standard	N/A	N/A	Option	Option	N/A
Ground Ball Screw	N/A	N/A	N/A	Standard	Standard	N/A	Standard	Standard
Belt Drive	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Rolled Ball Screw	N/A	N/A	Option	Option	Option	Standard	N/A	Option
Repeatability – in	0.001	0.00005	0.0001	0.00005	0.00005	0.0002	0.00005	0.0001
Accuracy – in/in	0.0002	0.00008	0.0002	0.00004	0.00005	0.00024	0.00008	0.00008
Straightness/ Flatness – in/in	0.0002	0.00008	0.0005	0.00004	0.00004	0.00008	0.00008	0.0001

Note [1] With 5 pitch or 4mm-nominal 12 inches travel

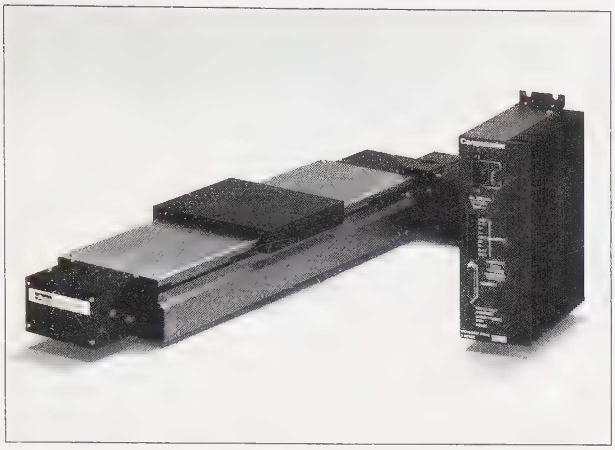


Cross roller



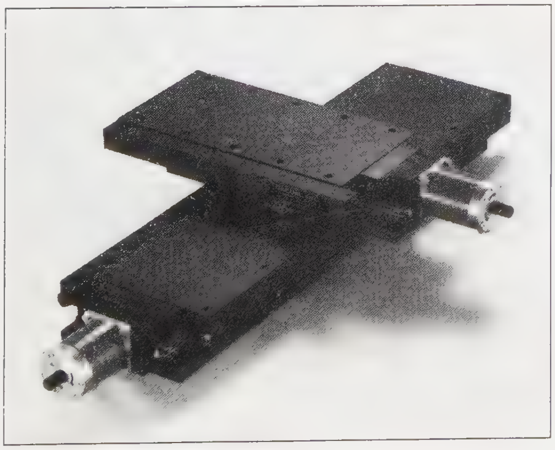
Square rail

Positioning Tables



Belt drive

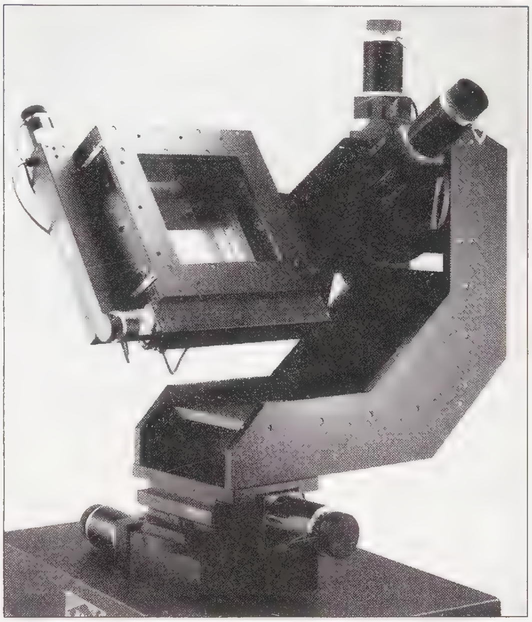
Open Frame		Rail	Belt
300000 Series		500000 Series	500000 PD
Standard	Precision	Standard	Standard
24	24	60	60
380	380	200	200
3	3	16	100
Standard	Standard	Option	N/A
Option	Option	Option	N/A
N/A	N/A	N/A	Standard
Option	Option	Standard	N/A
0.001	0.00005	0.0002	0.001
0.0002	0.00008	0.0002	0.0015
0.0005	0.0002	0.00015	0.00015



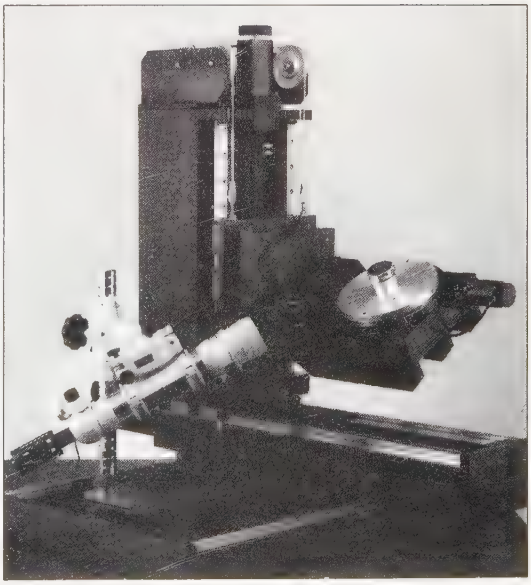
Linear ball bearing

Custom Tables

- Travels to 10 feet, width to 5 feet
- Payloads to 7,700 lbs
- Gantry and bridge designs
- 8 to 12 week delivery on custom designs
- Brakes, counter weights, controls, motors, and encoders



6-axis inspection system



5-axis motorized system with Z-axis counterbalance

Daedal Division
Box 500
Harrison City, PA 15636
800-245-6903

Parker

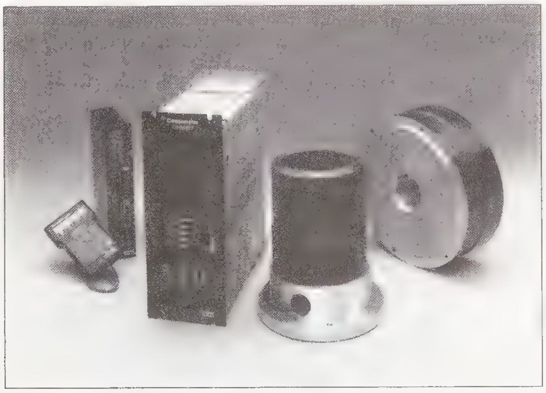
Circle 109

Daedal

Rotary Positioning Systems

Rotary Tables

- Pre-loaded worm gear drive
- 360 degree travel; accuracy to 2 arc-sec
- Gear ratios of 36, 45, 90 or 180 to 1
- Diameters to 12 inches, solid top or through hole
- Payloads to 200 lbs
- Standard ball bearing and heavy duty ball bearing models



Dynaserv

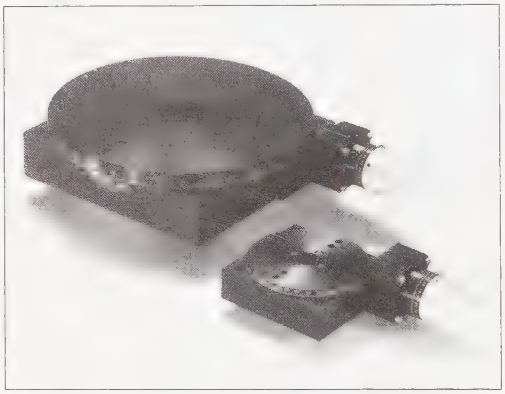
Direct Drive Motor

- Zero backlash
- Two arc-sec repeatability
- Torques up to 368 lb-ft
- Compression loads up to 8800 lb
- Overhung loads up to 150 lb-ft
- Drive/motor specifications on page 3

Rotary Tables

Rotary Stages

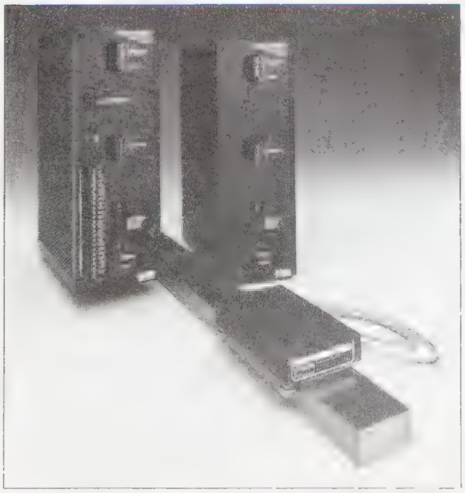
- 360 degree rotation
- Load capacity to 200 lbs
- Resolution to 0.002 degrees
- Precision or standard models
- Stage diameter to 12 inches, solid top or through hole



Rotary Stages

Compumotor

Linear Motors



Linear motors

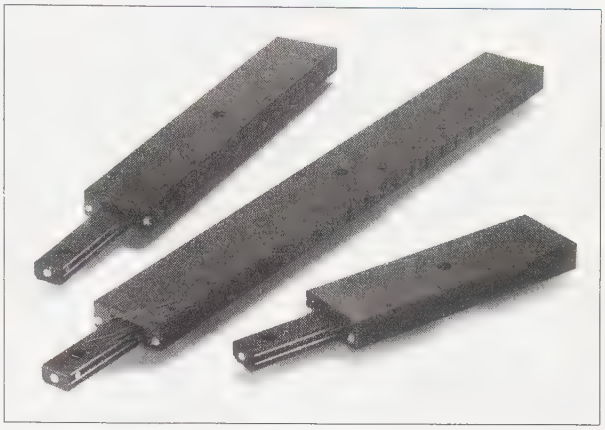
Model	L20
Static force – lbf	20
Resolution – steps/inch	5000–12500
Repeatability – inch (unidirectional)	±0.0001
Speed in/sec (@ 10000 steps/in)	75
Bearing type	Air–top Ball–side
Bearing load – lb	50–top 5–side
Standard lengths– inches	18–144

Each model is available with step and direction input, microstepping drive (Model L) or microstepping drive with integral RS-232C compatible indexer (Model LX). See page 6 for more drive specifications.

Circle 10

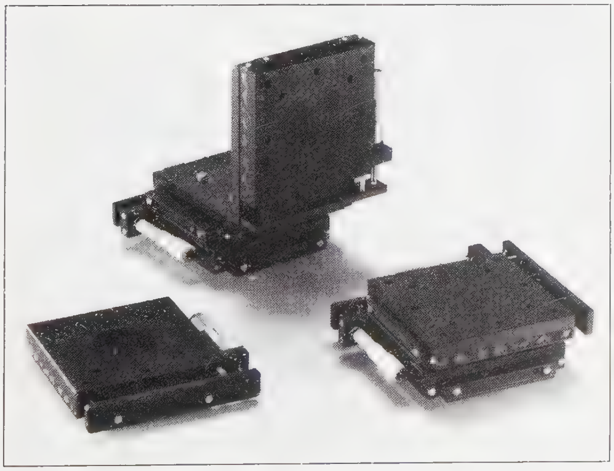
Manual Positioning Slides & Stages

- Straight line accuracy 0.00008/inch, repeatability of 0.00005
- Miniature ball slides
- Precision ground mounting surface with metric mounting holes
- English and metric micrometers, fine screw, and differential screw stages
- Digital micrometers with 0.0004 inch resolution
- In stock for immediate delivery

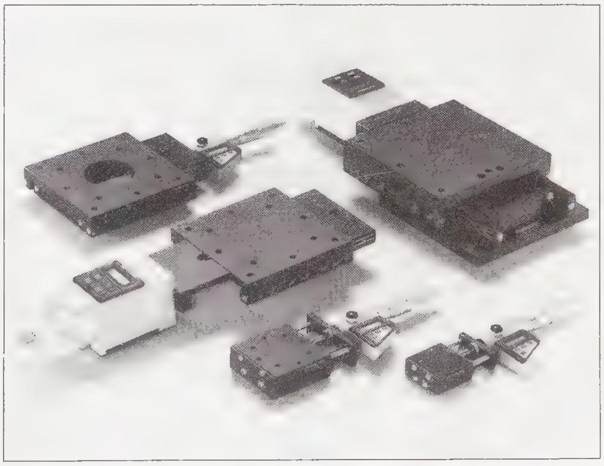


Positioning slides

				Dimension Ranges		
		Load Range (lb)	Maximum Travel (in)	Length (in)	Height (in)	Width (in)
Slides	Miniature ball	4-30	4	1.06 6.00	0.32 0.53	0.56 1.06
	Ball bearing	6-375	31	1.25 36.0	0.5 2.0	2.62 6.0
	Cross roller	50-280	12	1.75 18.0	1.0 2.0	1.75 6.0
Stages	Ball bearing	6-100	2	1.25 6.0	0.5 2.0	1.25 6.0
	Cross roller	15-220	2	1.75 18.0	1.0 2.0	1.75 6.0
Digital micrometer stages	Ball bearing	22-123	2	1.75 6.0	1.0 2.0	1.75 6.0
	Cross roller	22-242	2	1.75 6.0	1.0 2.0	1.75 6.0



Positioning stages



Digital micrometer positioning stages

Daedal Division
Box 500
Harrison City, PA 15636
800-245-6903

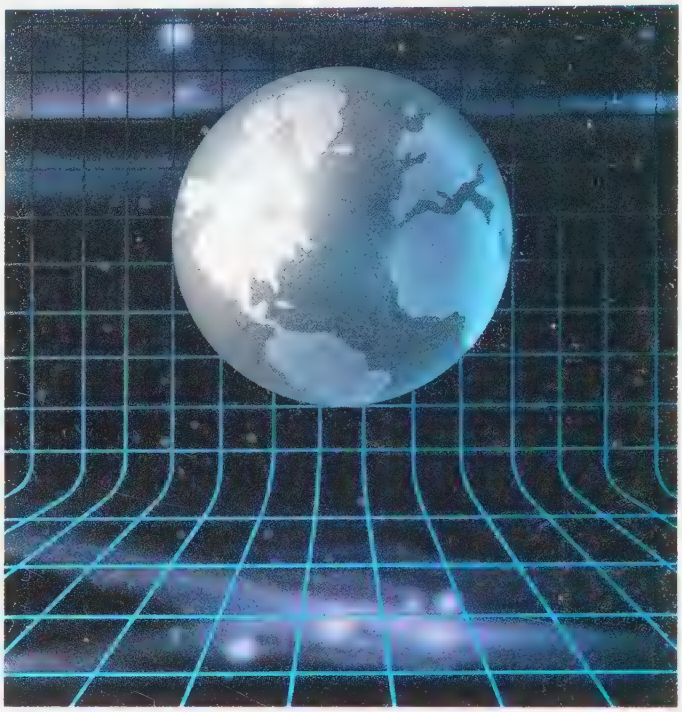
Parker

Circle 100

Unrivalled Worldwide Support Network

At Compumotor, Daedal, and Digiplan we understand the demands of the positioning systems marketplace. Throughout Europe, the Pacific Rim and North America our products are delivered and supported through a comprehensive network of factory-trained Automation Technology Center engineers. In addition to the services offered by traditional distributors, these organizations specialize in the application of high technology automation equipment. They offer local product availability, product demonstrations, complementary products and services, programming assistance, and in-depth customer seminars.

Every company promises service, but Compumotor, Daedal, and Digiplan have the people to assure timely, expert support. For example, there are more than 30 college and university engineering graduates in North America with factory training. These direct field application engineers are ready and prepared to offer assistance in product selection, installation, and product/system programming.

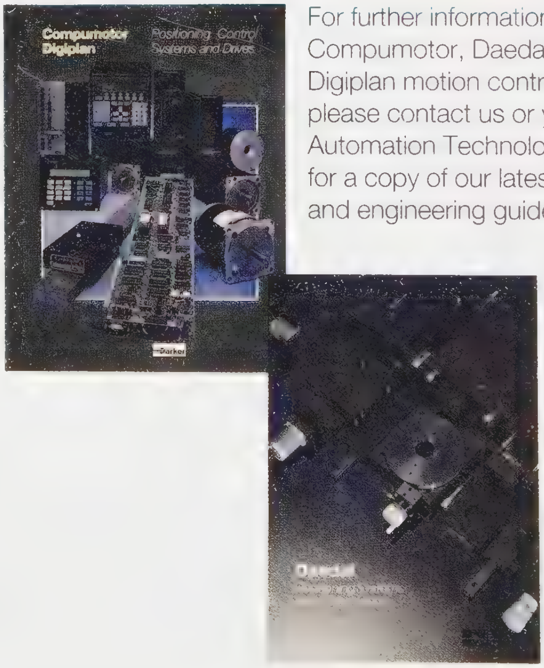


Automation Technology Center Locations

- Australia
- Belgium
- Canada
- China
- Denmark
- Finland
- France
- Germany
- Holland
- Hong Kong
- India
- Indonesia
- Ireland
- Israel
- Italy
- Japan
- Korea
- Malaysia
- New Zealand
- Pakistan
- Philippines
- Puerto Rico
- Singapore
- South Africa
- Spain
- Sweden
- Switzerland
- Taiwan
- Thailand
- United Kingdom
- United States

Complete Engineering Specifications

For further information on Compumotor, Daedal, and Digiplan motion control products please contact us or your local Automation Technology Center for a copy of our latest product and engineering guides.



Compumotor Division
5500 Business Park Drive
Rohnert Park, CA 94928 USA
800-358-9070
FAX 707-584-8015

Daedal Division
Box 500
Harrison City, PA 15636 USA
800-245-6903
FAX 412-744-7626

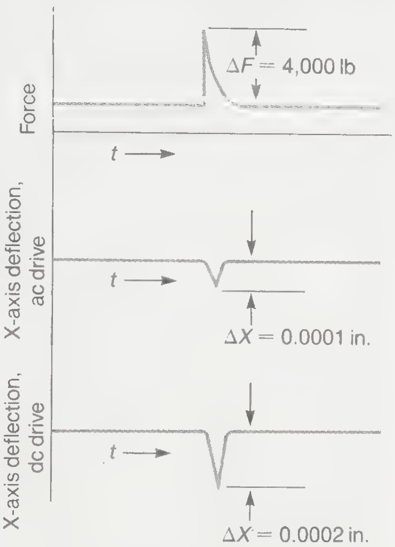
Digiplan Division
21 Balena Close, Poole
Dorset, England BH177DX
(0202) 69 9000
FAX (0202) 69 5750

DYNAMIC STIFFNESS DEFINED

Dynamic stiffness indicates how well a servosystem maintains position in response to an impulse load. In general, greater bandwidth and higher gain values provide greater dynamic stiffness. This can be quantified by measuring the impulse load force and dividing it by the deflection distance.

Mechanical or electronic deadband in the feed drive system will show up as a tool mark at the peak or crossover point in a contour cut. The depth of the mark is a function of dynamic stiffness and physical traits such as drivetrain backlash. If mechanical stiffness is infinite, surface finish is strictly a function of dynamic stiffness. As dynamic stiffness goes up, the size of tool marks decreases.

IMPULSE LOAD RESPONSE EXAMPLE

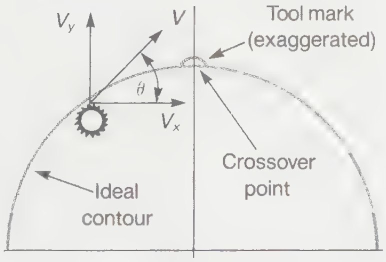


Dynamic stiffness = ΔF/ΔX

Ac = 40×10^6 lb/in. Dc = 20×10^6 lb/in.

Ac servos have greater dynamic stiffness than dc servos and deflect less under load. In this case, an impulse load of 4,000 lb was applied to the X-axis equipped with an ac and then a dc drive. The deflection was half as large with the ac drive.

CROSSOVER DISTORTION



At the crossover point, any system deadband — mechanical or electronic — will cause a tool mark. In this example, the Y-axis controller makes very small moves around zero, an area where gain is lowest. This results in electronic deadband. Ac servos run higher gains than dc servos and, consequently, leave smaller tool marks.

that they can compensate for changes at their input that are within the system bandwidth. But these changes are comparatively small. Such systems can become unstable for large input swings, or may simply be unable to compensate for sufficiently large input changes.

There are two main approaches to adaptive feedback-control design: model reference adaptive control (MRAC) and self-tuning regulators (STRs). In MRAC, a reference model describes system performance. The adaptive controller is then designed to force the system or plant to behave like the reference model. Model output is compared to the actual output, and the difference is used to adjust feedback controller parameters.

Most work on MRAC has concerned the design of the adaptation mechanism. This mechanism must note the output error and determine how to adjust the controller coefficients. It must also remain stable under all conditions. One problem with the approach is that there is no general theoretical method of designing an adapter. Thus, most adapter functions are specially keyed to some kind of end application.

An advantage of MRAC is that it provides quick adaptations for defined inputs. A disadvantage is that it has trouble adapting to unknown processes or arbitrary disturbances.

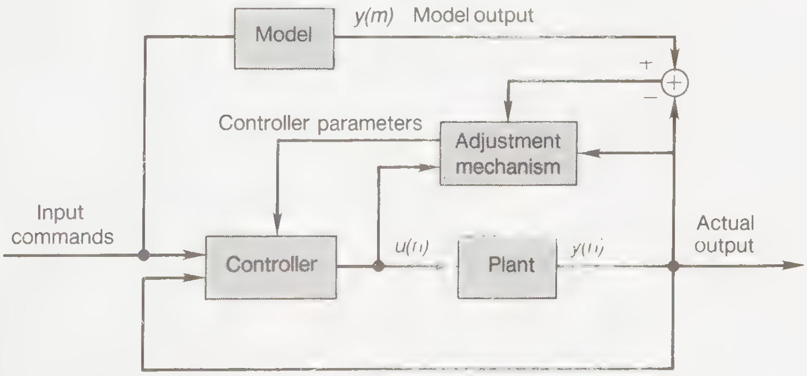
Model-reference controllers have an adaptation mechanism. The comparable component in self-tuning regulators is a tuning algorithm. A self-tuning regulator assumes a linear model for the process being controlled (which is generally nonlinear). It uses a feedback-control law that contains adjustable coefficients. Self-tuning algorithms change the coefficients.

These controllers typically contain two loops, one called inner, the other outer. The inner loop consists of an ordinary feedback loop and the plant. This inner loop acts on the plant output in conventional ways. The outer loop adjusts the controller parameters in the inner feedback loop. The outer loop consists of a recursive parameter estimator combined with a control design algorithm.

The recursive estimator monitors plant output and estimates plant dynamics by providing parameter values in a model of the plant. These parameter estimates go to a control-law design algorithm that then sends new coefficients to the conventional feedback controller in the inner loop.

Among the advantages of self-tuning control is that the algorithms are usually simple. Little or no prior informa-

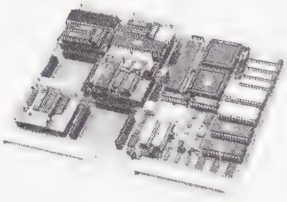
MODEL-REFERENCE ADAPTIVE CONTROLLER



A typical model reference adaptive-control system compares the output of the model, y(m), with plant output, y(n). Observed differences are used to adjust the controller parameters so that the plant will emulate the reference model. The approach has the advantage of quickly adapting to defined inputs. It has the disadvantage of not always behaving well when forced to deal with unknown processes or unanticipated disturbances.

Position and/or Velocity

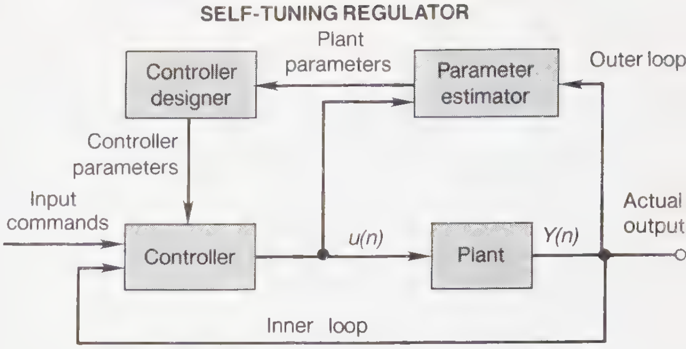
Motion Control



- Intelligent, state-of-the-art, DSP Multifunction Programmable **MOTION CONTROL** boards.
- For **PC-bus, VME-bus** and **"Stand-alone"** use.
- Control 1-8 motors with one board. Mix & match DC Servos & Steppers.
- 4-36 Analog I/O and 16-144 Digital I/O included per board. Plug-compatible with Opto22.
- C, Basic, and Turbo Pascal software. AutoCAD, G-Code, CNC, and interactive Servo-Tuning utilities.

Precision MicroControl
CORPORATION
8122 Engineer Road • San Diego CA 92111
Tel (619) 565-1500 • FAX (619) 565-1511

Circle 110



A self-tuning regulator is characterized by inner and outer loops. The inner loop is a conventional feedback loop in which a controller operates a plant. The outer loop controls the controller. In principle at least, such systems can adapt to any unknown process or disturbance.

tion is required about the process. Also, the techniques come from discrete-time stochastic control theory in ways that can be easily implemented on computers.

Self-tuners are sometimes started by having the initial control by open loop or manually controlled. This provides a preliminary estimation period. Once an initial set of parameters has been established, the loop is closed and controlled with the derived self-tuning algorithm. ■

Now ETP Bushings
Mount Your Shaft Components
Easier, Faster And More Precisely...

...Without Troublesome Keyways and Tapers.

Features double-walled sleeve, pressure ring and tightening screws. Slides on a shaft easily, and securely locks in position cams, pulleys, flexible couplings, gears and other shaft-mounted, motion control components.

When the Bushing screws are tightened, the sleeve expands and produces a solid connection between shaft and hub.

Adjusts radially and axially. Has excellent concentricity and produces no wear to the shaft. It costs more; but then again, it does so much more!

Twenty-six sizes from ¾" up to 4", plus metric sizes from 8mm to 110mm. Plus specials.

Call 1-800-533-1731 for FREE BROCHURE.

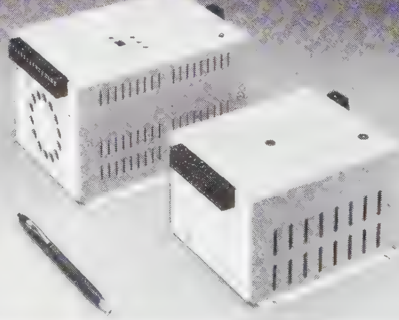
2845 Harriet Avenue South • Minneapolis, MN 55408-2291
(612) 872-6300 • TWX 510 601 5531 • FAX (612) 872-0472

ZERO-MAX / HELLAND
MOTION CONTROL PRODUCTS

© 1990

Circle 111

NEW HIGH-PERFORMANCE STEP MOTOR DRIVER PACKS



DPL SERIES: .5 TO 3 AMPS PER PHASE
DPM SERIES: .25 TO 2.5 AMPS PER PHASE

Series DPL and DPM Driver Packs operate 4-phase step motors, providing improved motor speed torque (power) output and higher start-stop speeds. High wattage dropping resistors are not required with these bilevel drivers.

Check These Features: • Compact and Rugged • TTL-MOS Compatible Inputs • Motor Turnoff Provisions • Full and Half-Step Operation • Reduced Power Requirements • Unregulated 12Vdc Output • Onboard Regulated +5Vdc Output • No Internal Wiring Required (DPM) • Integrated Power Supplies (DPM) • Onboard Pulse Generator, Bridges and Filter Capacitor (DPL)

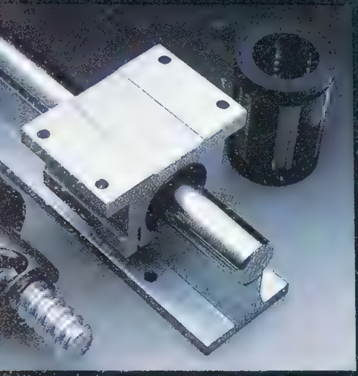
Call or write for brochure and prices.

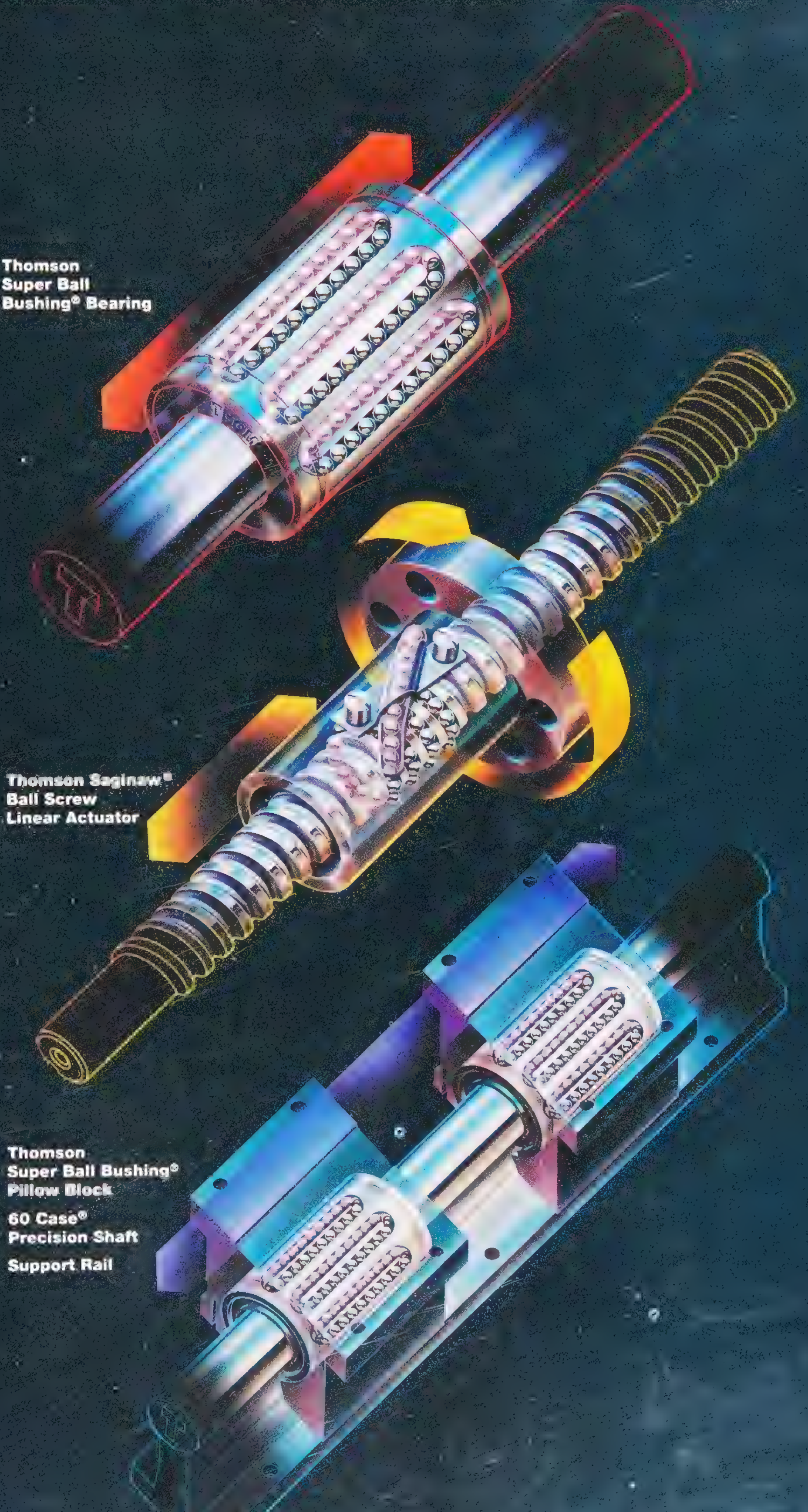
ANAHEIM AUTOMATION
910 E. Orangefair Lane, Anaheim, CA 92801
(714) 992-6990 • FAX (714) 992-0471 • Telex 2978217 MCI

Circle 112

THOMSON®

First in Linear Motion Technology





Vhen you need dependable near motion products, the hoice is clear... Thomson ndustries, Inc., the innovator in nti-friction linear motion. Since he introduction of the Linear Ball Bushing® bearing in 1944, ve continue to lead the industry ve created with new products and technologies to help you lesign better, easier and more efficiently.

For components, ready-to-nstall systems, and answers to your toughest linear motion questions, call us. The Thomson group of industrial companies specializes in solving your problems with the highest quality products available, from Ball Bushing® bearings and 60 Case® shafts, to advanced ball screw actuators and Powerslide® linear motion systems. Thomson s your first and best choice for inear motion components and echnology. Call 1-800-645-9357 oday for the name of the authorized Thomson distributor nearest you. Or write Thomson ndustries, Port Washington, NY 11050.

THOMSON®
INDUSTRIES, INC.

Thomson Linear Motion Components and

Linear Bearings and Components

Smooth, accurate, friction-free linear motion

We invented the Ball Bushing* bearing in 1945 and changed the way industry approached the problem of sliding friction. Today, Thomson Industries offers the broadest selection of anti-friction linear bearings and components. From our small, extremely precise Instrument Bearings to our high load, heavy duty Roundway* II linear roller bearings, Thomson has a solution to your linear motion requirements. Our high efficiency, self-aligning Super Ball Bushing* linear bearings offer 3 times the load capacity or 27 times the travel life of conventional linear ball bearings. A full line of advanced, related accessories and components maximizes design efficiency and reliability. Thomson products also offer the RoundRail* Advantage for reduced installation time, and lower cost. ***LINEARFAX*** No. 10078

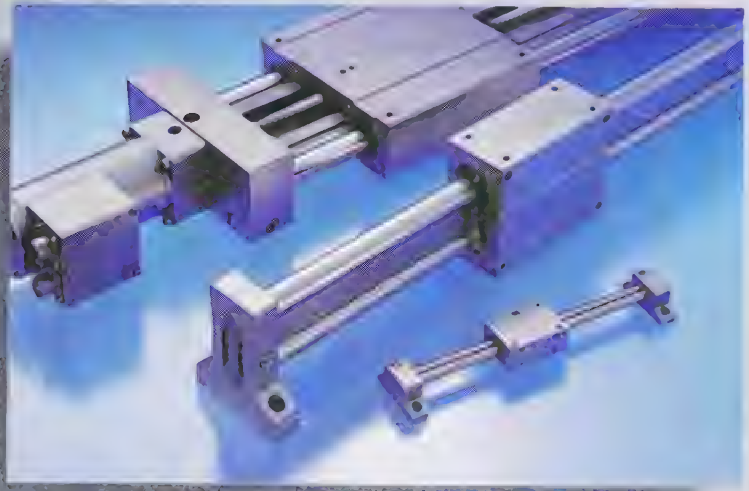
Circle 667

60 Case Shafting

The recommended inner race for all Thomson linear bearings

We recommend 60 Case* shafts because they offer superior surface hardness, smoothness, and straightness. This translates into better bearing performance and longer bearing life. Hardened for maximum strength, Thomson 60 Case shafts provide three times the tensile strength of unhardened shafts. 60 Case shafts also feature the Thomson Microbrite* surface finishing process. Microbrite results in a surface finish of 10-16 microinch, rms, for maximum accuracy and minimum wear. Thomson 60 Case shafts are also a cost-effective answer to other bearing applications. From piston rods to spindles, 60 Case shafting provides improved performance and function. Thomson 60 Case shafts are available for immediate shipment from stock in diameters from 1/8 in. to 4 in. They are available in cut-to-length, predrilled, tubular and custom-machined versions. 60 Case shafts are also available in corrosion resistant 440C material and chrome-plated steel. ***LINEARFAX*** No. 10178

Circle 668



Linear Motion Systems

Pre-assembled and ready to install

Thomson systems provide precise linear positioning in complete, ready-to-use, cost-effective, pre-engineered packages. By employing quality Thomson systems in their designs, engineers reduce design time, improve machine performance and reduce total project cost. Systems are available in a variety of configurations with ball screws, motors, and controllers. Systems are available in fully supported, unsupported, and end-supported configurations, as well as ready-to-bolt down systems with factory-aligned shafts. There's a Thomson linear motion system available to fit every application. Featuring load capacities of up to 6,200 pounds with unlimited travel lengths, Thomson systems are the perfect solution to your automation needs. ***LINEARFAX*** No. 10378

Circle 669

Systems

Easy as 1-2-3! To use *LINEARFAX* Technical Data:

1 Call 1-800-554-THOMSON for the main menu, 24 hours a day.

2 Follow phone prompts to select the product menu you want.

3 Enter the 5-digit document number. Input your fax number. Your data is sent immediately.

Thomson Saginaw Ball Screws and Linear Actuators

Over 50 years of quality, dependability, and performance

Thomson Saginaw* pioneered the first ball screw in 1941, and has continued to lead the way in performance and reliability. Built to handle the highest performance design standards, Thomson Saginaw Precision Plus* ball screws feature select lead accuracies of 0.0002 inches per foot, providing consistent and precise linear travel. Metric versions conform to ISO Class 25, 50, and 100. Standard ball screws are available with lead accuracies of 0.001 inches to 0.004 inches per foot, in adjustable preloaded or non-preloaded ball screw nut configurations. Thomson Saginaw ball screws operate at over 90% efficiency and are virtually maintenance-free. Thomson PPA linear actuators combine Thomson Saginaw ball screws with electric motors and gear boxes for precise linear actuation. PPA Actuators are designed to offer a variety of optional position sensors, providing highly-precise linear actuation in a ready-to-install, low-maintenance package. ***LINEARFAX*** No. 10678

Circle 670

Metric Products

Linear bearings and components now in metric sizes

All the quality and performance you expect from Thomson, but engineered to metric-dimensions. Thomson's new Super Plus Ball Bushing* metric linear bearings use ground bearing plates for increased accuracy and smoothness. Extremely rigid MultiTrac* bearings offer twice the load carrying capacity of conventional linear metric bearings. Matched metric diameter components, including 60 Case hardened and ground shafting (in diameters between 5mm and 80mm), factory-installed pillow blocks, support blocks, and support rails, are available as well.
LINEARFAX No. 10278

Circle 671

AccuGlide Linear Ball Bearing System AccuMax Linear Roller Bearing System

Meet Thomson's new family of rail-type products. AccuGlide* Ball Bearing Systems, available in 25mm, 35mm, and 45mm sizes, provide high load capacities in all directions. They're fully interchangeable with existing ball guide systems. The low profile lets designers optimize machine compactness and performance. They're perfect for applications such as lathes, milling machines and machining centers. For applications such as wafer processing equipment, optical insertion equipment, and electronic instrumentation, consider the AccuGlide Miniature Ball Bearing Systems, available in 10mm, 15mm, and 20mm sizes. For uncompromising quality and performance, there's AccuMax* Roller Bearing Systems, based on Thomson's exclusive, patented Arcuate Technology. AccuMax Bearing Systems offer up to twice the load capacity of equal-sized ball bearing systems for dramatic improvement in system life, and reduction in maintenance. They also provide greater rigidity than conventional ball-based linear guide systems for immediate improvements in machine performance. ***LINEARFAX*** No. 10478

Circle 672

Nyliner Bearings

High-performance, low-cost thermoplastic bearings

The ideal alternative to conventional bronze or metal bushings. Precision molded from high quality engineering polymers, both Nyliner* and Nyliner Plus* bearings offer extremely low coefficients of friction for smooth, accurate linear, rotary, or oscillating motion. Designed to operate efficiently at temperatures up to 500° F, the bearings require virtually no lubrication for optimum service life. Available in seven standard configurations and custom designs. ***LINEARFAX*** No. 10578

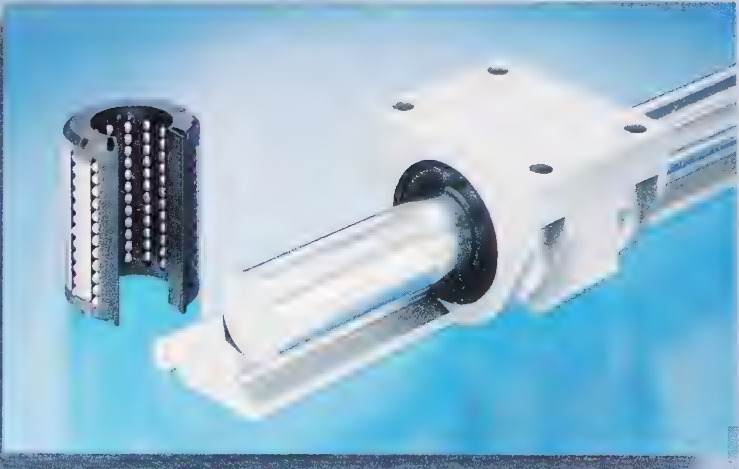
Circle 673

Precision Balls

A comprehensive line of standard and custom balls

Thomson Precision Ball Company offers a wide variety of standard and custom balls. Precision high-carbon steel and stainless steel balls are available in diameters as small as .005" in Grades 3 to 200. Newly available, hollow balls for precision, weight-sensitive applications. Balls are manufactured in ferrous, non-ferrous and ceramic materials, and all are guaranteed to meet strict AFBMA standards. ***LINEARFAX*** No. 10778

Circle 674



Ultra Ball Bushing Linear Bearing System

375 times more travel life and 7 times the load capacity of conventional linear bearings

Every Ultra Ball Bushing* Linear Bearing System is comprised of two or more steel pillow blocks complete with a factory-installed Ultra Ball Bushing bearing, seals, case-hardened and precision-ground 60-Case shaft, and a rigid steel support rail. The Ultra Ball Bushing Linear Bearing employs ten working ball tracks to provide superior load capacity and travel life over conventional linear bearings. When replacing high friction plain bushings, Ultra Ball Bushing linear bearing systems allow the use of smaller, less expensive drive units. Ultra systems eliminate the high friction, stick-slip and lubrication problems associated with v-way or flat-way systems. The Ultra bearing system can also achieve high operating speeds without the need for derating factors commonly seen with linear guides. ***LINEARFAX*** No. 14078

Circle 675

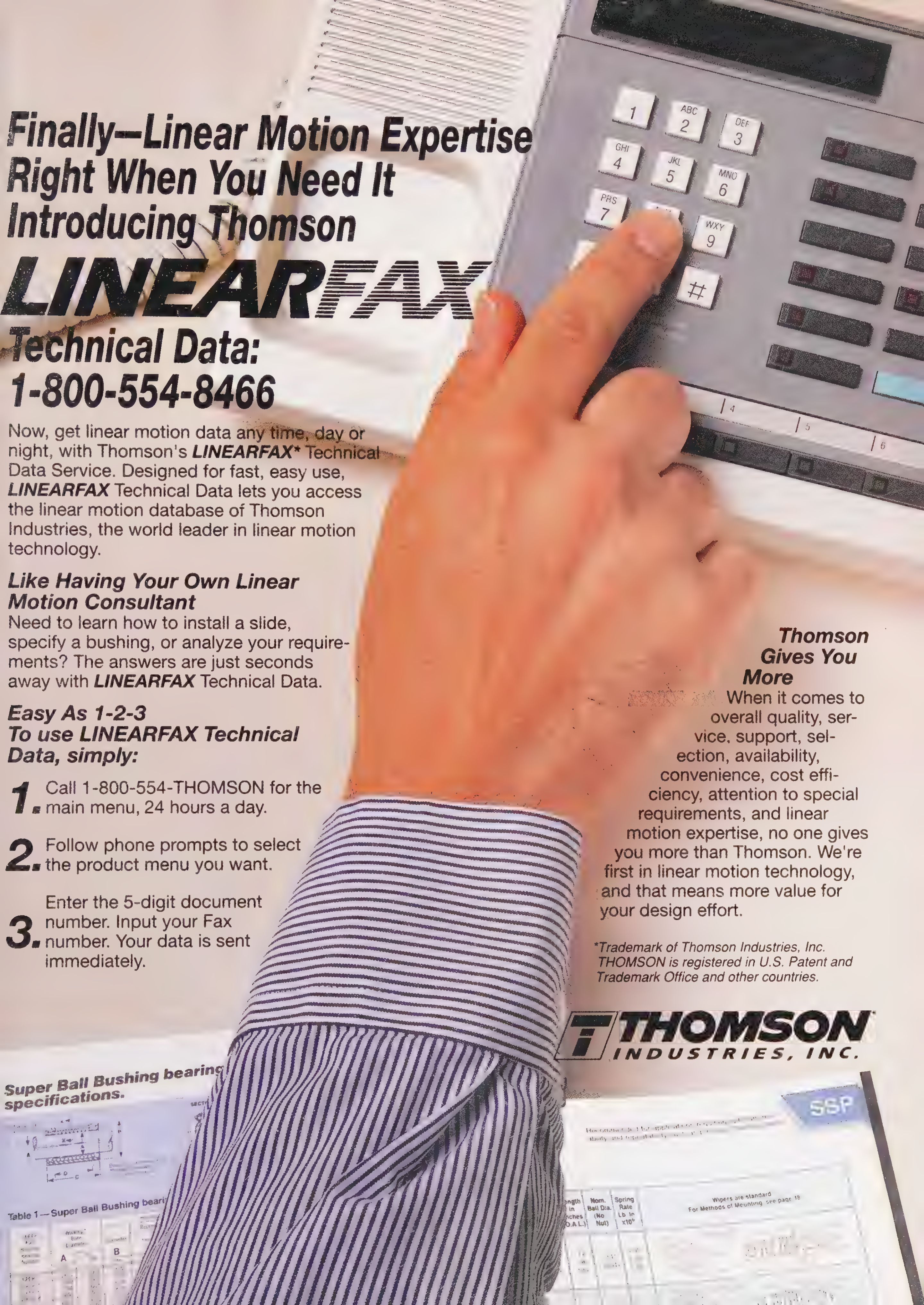
**THOMSON*
INDUSTRIES, INC.**

*Trademarks of Thomson Industries, Inc. Thomson is registered in U.S. Patent and Trademark Office and other countries.
© Thomson Industries, Inc.

FOR IMMEDIATE ASSISTANCE

Phone: 516-883-8000
Fax: 516-883-9039

Or Write: Thomson Industries, Inc.
Port Washington, NY 11050


Super Ball Bushing bearing specifications.
Table 1—Super Ball Bushing beari
SSP
Wipers are standard
For Methods of Mounting, see page 18

Finally—Linear Motion Expertise Right When You Need It
Introducing Thomson LINEARFAX Technical Data: 1-800-554-8466

Now, get linear motion data any time, day or night, with Thomson's ***LINEARFAX**** Technical Data Service. Designed for fast, easy use, ***LINEARFAX*** Technical Data lets you access the linear motion database of Thomson Industries, the world leader in linear motion technology.

Like Having Your Own Linear Motion Consultant

Need to learn how to install a slide, specify a bushing, or analyze your requirements? The answers are just seconds away with ***LINEARFAX*** Technical Data.

Easy As 1-2-3 To use LINEARFAX Technical Data, simply:

1. Call 1-800-554-THOMSON for the main menu, 24 hours a day.
2. Follow phone prompts to select the product menu you want.
3. Enter the 5-digit document number. Input your Fax number. Your data is sent immediately.

Thomson Gives You More

When it comes to overall quality, service, support, selection, availability, convenience, cost efficiency, attention to special requirements, and linear motion expertise, no one gives you more than Thomson. We're first in linear motion technology, and that means more value for your design effort.

**Trademark of Thomson Industries, Inc. THOMSON is registered in U.S. Patent and Trademark Office and other countries.*

THOMSON
INDUSTRIES, INC.

Motion controllers

Motion control today takes place under the guidance of computers, solid-state logic, or pneumatic sequencers. These devices can take on a variety of forms and provide control on different levels.

Controllers can be divided into four basic types. *Chip-level* devices consist of a few integrated circuits combined to produce signals that drive positioning equipment. *Board-level* devices are controllers made up of one or more circuit boards containing computer functions as well as input/output (I/O). These devices often handle control, sensing, and power drive for positioning equipment. *Box-level* devices generally combine displays, keyboards, computing, and I/O functions into a single enclosure. Finally, *dedicated* controllers include programmable logic controllers (PLCs) and pneumatic sequencers. These are designed to handle specific chores common to factory-floor control.

Devices in each of the four categories play a different part in motion control. As an overview of the technology, we will outline capabilities that typify equipment applications for each type.

Microcontrollers

Motion controllers built up from integrated circuits frequently use single-chip microcontrollers as the main source of computing power. These devices are essentially computer processors, memory, and simple input/output functions combined on a single chip.

Microcontrollers developed in the past few years are frequently used in motion-control applications because they contain several features optimized for such uses. These features often include special timers and counters. The timers and counters are set up to facilitate the generation of pulse-width-modulated (PWM) waveforms used to drive motors and other industrial loads.

Additional features encountered in such microcontrollers include special facilities for both rapidly sensing signal levels on input lines, and for generating trigger signals to start external peripherals. These features are aimed at timing mechanical peripherals such as rotating machinery and for sensing signals generated by transducers such as limit switches. Additional capabilities aimed at control applications typically may include dedicated PWM outputs, watchdog timers, and high-resolution (on the order of 10-bit) analog/digital converters.

Microcontrollers now commonly built into motion-control applications include 8096, 8051, and 68HC11-type devices. These components work with either 8-bit or 16-bit data paths at clock rates as high as 12 MHz. The throughput and bandwidth that such facilities provide is considered adequate for the majority of simple motion-control applications. However, fast 32-bit controllers have also been introduced in the past year that are aimed specifically at handling high-end needs.

The 32-bit parts designed for these applications often contain scaled-down computing facilities found in general-purpose 32-bit microprocessors. Keys to high performance generally include multimegabyte address space, 32-bit data handling, clock rates on the order of 16 MHz or more, and special instruction sets. Such facilities enable such chips to directly address extremely large memories and run lengthy programs. Controllers in this category include the 80960 and 80376.

Other features found in such devices, and on peripheral chips optimized to work with the controllers, include direct memory-access (DMA) channels, interrupt controllers, and programmable interval timers. Applications are typically those that demand numerous calculations or image recognition. Examples are robotic arm control or array processing.

Special ICs

Manufacturers have also developed special-purpose ICs that handle tasks needed to implement both closed-loop motion control and motor speed control. Presently, three chips are available for closed-loop control, one for multiaxis contouring, and a few others for motor speed control.

A general-purpose motion-control IC

DIGITAL SIGNAL PROCESSORS

Advanced control algorithms, as used in digital filtering and discrete Fourier transforms, demand numerous multiplication and additions. When done in software on an ordinary processor, these operations can consume too much time to provide high-speed control.

An approach to solving the speed requirements associated with modern control algorithms is to use a special kind of processor chip. Digital signal processors (DSPs) are constructed to speedily perform the kinds of arithmetic operations associated with digital filtering and processing. Most DSPs are built with what is called a Harvard architecture. This configuration is unlike conventional computer architectures in that it employs separate data and instruction memories that are accessed by separate buses. The benefit of this arrangement is increased speed because instructions and data can move in parallel instead of sequentially.

In addition, these ICs generally carry high-speed hardware multipliers and fast on-chip memories that eliminate delays associated with shuttling information on and off chip to peripheral devices. This promotes fast program execution.

For example, a DSP can fetch an instruction while loading two numbers into its multiplier. An ordinary processor such as a 6800 might consume as many as 80 clock cycles to multiply two numbers and add the result to an existing sum. A DSP chip such as the TMS320C25 can do the same clock cycle covering about 100 ns.

DSPs take the form of single-chip ICs, specialized board-level computers, and bit-slice chips optimized for signal-processing operations. Of these, single-chip versions are the most widely used because their low cost makes digital signal processing practical in a variety of applications, ranging from consumer electronics to automotive engine control.

DSP architecture arises from the calculation sequence used to synthesize called the HCTL-1000 is aimed at dc, brushless dc, and stepper motors. The TTL-compatible chip is powered by a single 5-V power supply. Position and velocity control are provided by comparing the (host) computer-command signal with feedback data from an incremental encoder. The encoder feedback is decoded into quadrature counts and a 24-bit counter keeps track of position. As a result, neither analog compensation nor velocity feedback is necessary.

On-chip software allows a choice of four control modes: position control, proportional velocity control, trapezoidal profiling, and integral velocity control.

In the position-control mode, the motor moves from one point to another without velocity profiling.

Proportional velocity control regulates motor speed using only gain for compensation. Dynamic pole and zero-lead compensation is not used. Actual motor velocity is compared to the specified velocity, and the error calculated.

The trapezoidal mode is used for point-to-point control with velocity control. The final position, acceleration, and maximum velocity are specified. The controller then computes the signal profile needed to conform to these requirements. Motor velocity is monitored during the position change. If maximum velocity is reached before the motor moves half way to the target position, the velocity vs. time waveform is trapezoidal. Otherwise it is triangular.

Continuous velocity control is provided by the integral velocity control mode. Here, velocity and acceleration can be changed at any time to profile velocity in time. Once the specified velocity is reached, it is maintained until the command is changed.

Another closed-loop controller, called the GL-1200, produces precise motor control using an external 10-MHz clock which times the circuit output. The chip compares signals generated by a two-channel incremental encoder with the specified position to generate a 12-bit error signal. The error signal provides motor position control. An interesting feature of the GL-1200 is that it calculates the derivative of the position error, and uses that value for system damping. Because the derivative is proportional to velocity, the need for velocity feedback from a tachometer is eliminated.

Recently developed servocontrol chips, called the LM628 and LM629, contain PID filtering functions. Filter constants can be changed on commands from a microprocessor during a move.

The host programs required velocity, acceleration, and position. The host can also program the coefficients of the digital filter used to provide gain, and compensate for following error and motor time constants. The host can interrogate the chip and read the position register and obtain other status information. The servo IC can interrupt the host in the event of critical situations as well, such as if position error exceeds certain bounds (as might occur if the motor stalls, for example).

During a move, a profile generator on the servo chip sends a position signal to a digital summing node. The required position is compared once per sample interval to the actual motor position. The resulting error signal goes through filtering before being sent to the digital/analog converter.

Several years ago, two chips were developed specifically to control simultaneous movement along two axes. There are two basic problems that these chips are designed to solve. To illustrate them, consider a milling machine that is to make a 45° cut, relative to the *X* and *Y* axis. Unless the motors driving the mill table finish at exactly the same time, the cut will not be a straight line. Instead, it might have a slight curve or actually resemble a staircase.

The other difficulty has to do with maintaining constant cutting-head speed. Actual cutting speed depends on the velocity in both the *X* and *Y* directions. In the example, if the cutting speed is specified as 10 ipm, and the head is moved in the *X* and Y directions at this speed, the actual speed would be 14.14 ipm.

The two chips, the KM3701 and KM3702, both are CMOS devices and can be obtained on PC-compatible plug-in boards as well as separately. The KM3701 microcontroller generates interpolation pulses for the *X* and *Y* axis. The information used to calculate the interpolation pulses is received from an external processor. These pulses can be used to control stepping motors in open-loop systems, or the KM3702 in closed-loop designs. The KM3702 is a motion-control chip that generates an output signal proportional to the difference between the specified position and the actual position.

Interpolation pulses are calculated from an algorithm stored on the chip. A feature that differentiates the KM3701 from other interpolation chips is its ability to generate pulses for parabolic, logarithmic, and exponential functions. This feature allows it to closely approximate complex curves such as those found on a wing spar, for example.

Several firms have developed chips for speed control. An example is the

digital filters and discrete Fourier transforms. These two functions form the basis for much of the digital signal processing now used in industry. The calculation sequence, in general terms, is one of a linear constant coefficient difference equation:

$$y(n) = -\sum_{k=1}^{N} a_k y(n-k) + \sum_{k=0}^{M} b_k x(n-k)$$

This equation basically says that any output y can be expressed as a weighted sum of the input x at the present time n, past inputs $x(n-k)$ for some number of past samples k, and past outputs $y(n-k)$. Terms a_k and b_k are the weighting factors. A computer optimized to quickly synthesize this equation must be able to store an input, multiply it by a weighting factor, and sum it with previous inputs.

DSP architecture provides these functions by incorporating a large degree of parallelism, carrying out multiple operations per machine cycle. The ability to perform parallel fetches from two registers and store the contents in two memory locations is an example. In addition, the memory on chip is extremely fast and constructed in ways designed to facilitate data transfers.

Because DSPs typically do not need to store large programs or blocks of data, they usually lack the extensive memory-management circuitry found in general-purpose microprocessors. Nevertheless, DSPs have become very powerful. The first such chips had only limited instruction sets and memory, and were limited to fixed-point (integer) calculations.

In contrast, DSP chips today are second and third-generation devices that eliminate such problems. They typically use clock rates of 20 MHz and 40-MHz clocks are not unheard of. Newer DSPs also provide on-board functions such as serial ports, analog/digital and digital/analog converters, EPROM, bit I/O timers, and similar functions that enhance capability.

TIPS ON CONSTRUCTING SINGLE-BOARD COMPUTERS

Manufacturers and users of industrial computer systems offer a few general guidelines that can aid in choosing among bus formats.

- In PC AT systems, buy the processor, memory, and I/O from a single vendor. Inadequate timing definitions for the PC AT bus can mean that high-speed CPUs and DMA peripherals may not work well together if they come from different sources. However, less time-critical I/O cards generally do not have such compatibility problems.
- Consider the need for industrial I/O. Widely used types of industrial I/O are often easier to find for STD systems than on PC bus cards, though the situation is changing quickly.
- Be careful in high-temperature applications. High-temperatures are more likely to exacerbate timing problems on PC AT bus systems running faster than about 8 MHz. Under these conditions, “typical” timing values tend toward “worst case.” Here, some experienced developers recommend bus formats that are more well defined, such as STD. These timing difficulties are likely to disappear when the AT bus specifications becomes an IEEE standard. A working group is in the process of defining such a standard, termed P996, which would alleviate problems brought about by inadequate timing definitions.
- Consider MBII and VME for high performance. Applications where a need for minimum hardware is not as important as the ability to work with high data rates on the order of 40M bytes/s are probably best served by these two bus standards. And MBII or VME is required for multiprocessing where CPUs work independently but must communicate over a backplane. Some applications that these two bus standards now service may eventually be candidates for systems based on the NuBus, a format which works at twice the speed of the Micro Channel and which is considered a medium-speed bus.

LS7263. Intended for speed regulation of three-phase, brushless dc motors, the circuit uses a 3.58-MHz crystal time base (as commonly used in color TVs) to produce ±0.1% speed control. Speed corrections are made by measuring the tachometer input and varying each winding’s drive signal. The chip provides positive braking by shorting the windings together. This places an electrical load on the motor and slows it down.

Overcurrent protection for the windings, drivers, and power supply is provided. This protection circuit uses a fractional-ohm resistor, connected between the positive supply and the driver’s emitters. A 100-kΩ potentiometer is connected between the driver and ground, with the wiper wired to the IC’s overcurrent input. The wiper tailors the activation current for a particular motor.

Board level

Board-level motion controllers typically contain one or more circuit boards mounted in a card-rack chassis. One of these boards generally holds the computer and memory hardware. Another holds the interface for any mass storage such as a hard-disk drive. Other boards may be used to provide input/output hardware for handling loads. For example, a three-axis controller might contain three separate I/O boards, one to drive each of the three axis motors.

Increasingly, board-level controllers are built to one of several industry standard bus structures. In simple terms, a bus is defined as a circuit that has a single format for all of the connected elements. Most computer systems have three buses: address, data, and control. Together these are defined as the system bus.

There are performance differences among the bus structures in use today. In addition, the board sizes for each format differ, making certain formats more optimum for some applications than for others. For example, formats specifying larger boards may be best in uses where it is desirable to combine as many functions as possible on a single board. On the other hand, smaller board formats may be better in situations where space is limited or where vibrations are too severe for large, unsupported circuit boards.

Input/output options for various formats differ as well. It may be possible to find a wide variety of motion-control boards for widely used industrial buses such as STD or Multibus I, but difficult to find the same equipment in Multibus II or VME, which are increasingly deployed in military systems.

The VMEbus is a standard designed by a consortium of companies. The objective of VME developers was to define a set of bus architectures that allows growth from one to another with no change in specification. VME provides 8, 16, 24, or 32-bit addressing. It is an asynchronous bus that allows block-mode transfers and unaligned transfers (where memory blocks do not begin on even-word boundaries).

An older standard called Versabus was designed to handle 68000-based designs. It has largely been supplanted by VME. One major advantage Versabus has over VME, however, is that it uses a larger board, thus allowing each board to contain more circuitry.

Multibus I was once the most widely used platform for 680X0 and 80XXX computer designs. The major strong point of Multibus I is simplicity. It has a 16-bit data bus, 24-bit addressing, an asynchronous protocol, and no multiplexing. It includes sub-buses for local memories. Several features have been added to the original specification to keep performance abreast of technology. For 8 and 16-bit computers, Multibus I is still competitive.

A newer standard called Multibus II is a synchronous bus with five levels of embedded sub-buses. The main bus is 32 bits wide and operates at 40M bytes/s (10 MHz × 32 bits). The local-memory bus is even faster, operating on a 12.5-MHz clock. Whereas an asynchronous bus simply creates wait states to deal with different device speeds, Multibus II solves the problem by using several sub-buses.

The real strength of Multibus II seems to be its potential for sophisticated multiprocessor design. No other bus offers quite as much capability for tightly coupled synchronous operation of many processors and many shared devices.

A number of manufacturers also make boards compatible with other buses such as Q-Bus. It was originally designed for LSI 11 microcomputers. Key attributes of Q-Bus include low cost and simplicity. To save signal lines, address and data are multiplexed. A 4M-byte memory capacity comes from the use of 22 address bits.

In terms of shear numbers, the PC is the most popular system ever built. The original PC and XT both have a 1M-byte address limitation, with only 640k bytes usable because of memory mapped I/O. Buses on PCs, XTs, and ATs are all synchronous. The PC uses an 8-bit data bus, whereas the XT and

Warner Electric Ball Bearing Screws Quick Selection Guide

WARNER ELECTRIC

DANA

449 Gardner Street, South Beloit, IL 61080
Call 800/234-3369. Ask for catalog P-978
815/389-3771 • FAX 815/389-2582

Circle 118

Warner Electric has the experience, engineering expertise, manufacturing capability and the product range to satisfy the most demanding linear motion applications. As a pioneer in the field, we are able to offer the designer the widest range of standard products in the industry...from rolled thread or high accuracy precision ground ball bearing screws to high helix positioning screws and ball bearing splines.

The ball bearing screws presented in this catalog represent years of experience in developing products to the highest standards of accuracy, precision and performance. If you don't find what you need, Warner Electric's design staff is ready to custom engineer a product that's exactly right for your requirements.

Warner Electric has developed eight distinct ball screw lines, each intended to address a different range of accuracy demands, design requirements and application needs. R series, RM series and M series ball screws are manufactured using a thread rolling process. GN series, GV series, MM series, RB series and P series ball screws are all manufactured by machining and precision grinding the threads on the screw stock. This method provides for a highly accurate, precision ball bearing screw. Ball screw accuracy is graded using ISO standards. Although, ISO standards cover a number of criteria related to the accuracy and tolerances of the entire ball bearing screw assembly, cumulative lead error (as listed in our features) is typically the most important criteria when selecting one model over another.

Our manufacturing facilities throughout the world ensure that we can supply the linear motion products you need, where ever in the world you may need them. The Warner Electric advantage goes far beyond design and manufacturing expertise. Our commitment to your needs is backed up by the largest staff of trained sales engineers in the industry. Furthermore, many of the standard products presented in this catalog are available from stock at nearly 500 authorized Warner Electric distributors in the United States and Canada.

Other linear motion products not featured in this brochure include Warner Electric's Electrak® linear actuators and Rapidtrak® rodless actuators. In addition, Warner Electric offers a complete ball bearing screw rebuild and reconditioning service featuring a new ball screw warranty. Contact your local Warner Electric representative or distributor for complete information on this service, as well as all other linear and rotary motion products.

ndustrial Grade

eries R

- preload/zero backlash assemblies available
- optional flanges available
- V threaded ball nuts

eries RM

- metric leads
- optional flanges available
- V threaded ball nuts

eries M

- industrial miniatures
- 0.006"/ft. lead accuracy standard
- super fines leads
- double nut preload housings available

eries PN High Helix Positioning Screws

- stainless steel screws
- composite nuts
- 60% minimum efficiency
- zero backlash nuts available

eries A Ball Bearing Splines

- high torque
- lengths up to 12 feet
- reliable, predictable life

Precision Grade

Series GN

- 0.0005"/ft. accuracy standard
- integral preload and double nut preloads available
- integral flanges standard
- preloaded base and flange mount housings available

Series GV

- 0.0005"/ft.accuracy standard, 0.0002"/ft. available
- integral preload available
- optional flanges available
- V threaded ball nuts

Series MM

- metric leads
- 0.0005"/ft. accuracy standard
- integral flanges standard
- integral and double nut preloads available

Series RB

- high lead/fast lead
- 0.0005"/ft. accuracy standard
- preloaded units available
- optional flanges available
- V threaded ball nuts

Series P

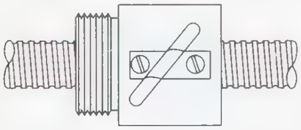
- precision miniatures
- 0.0005"/ft accuracy standard
- super fine leads
- double nut preload housing available

Circle 118

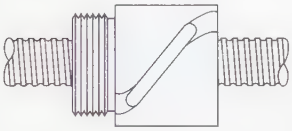
Product Selection Industrial Grade Ball Bearing Screws

Series R

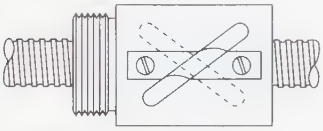
- 31 standard models
- Available in non-preload and preloaded/zero backlash ball nut assemblies
- Optional flanges available
- 5 left hand thread models
- 3 stainless steel models



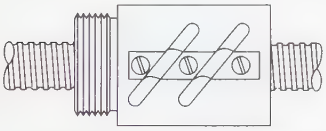
Single nut, non-preload, single circuit



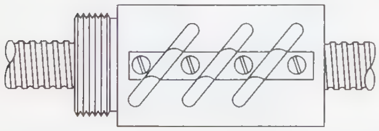
Single nut, non-preload, single circuit, recessed return tube



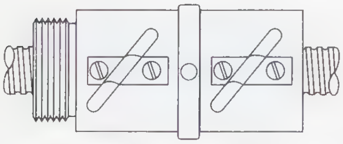
Single nut, non-preload, dual circuit



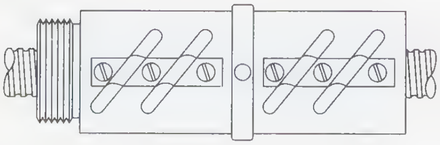
Single nut, non-preload, dual circuit



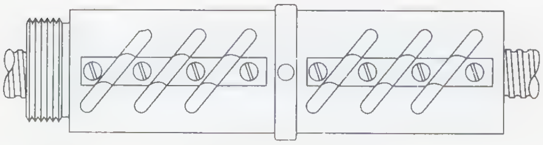
Single nut, non-preload, triple circuit



Double nut, preloaded, (2 single circuits)



Double nut, preloaded, (2 dual circuits)



Double nut, preloaded, (2 triple circuits)

							Preloaded/ZeroBacklashAssemblies		
Model No.	Screw Dia.	Lead	RH LH	Nom. Ball Dia.	Maximum Static Capacity Single Nut Non-Preloaded	RatedDynamic Load–Lbs@ 1,000,000" Travel Single Nut Non-Preloaded	Preload Model No.	Maximum Static Capacity (lbs) Double Nut Preloaded	RatedDynamic Load–Lbs@ 1,000,000" Travel Double Nut Preloaded
R-0308	.375	.125	RH	.078	4,250	500	RP0308	4,200	450
RC0308	.375	.125	RH	.078	1,760	235	—	—	—
R-0505	.500	.200	RH	.125	9,400	1,200	RP0505	9,280	1,080
R-0502	.500	.500	RH	.125	13,350	2,200	RP0502	13,130	1,980
RS0502	.500	.500	RH	.125	1,950	380	—	—	—
RC0605	.625	.200	RH	.125	6,150	800	RD0605	6,070	720
RQ0605	.625	.200	RH	.125	6,150	800	—	—	—
RK0605	.625	.200	LH	.125	6,150	800	RE0605	6,070	720
R-0705	.750	.200	RH	.125	18,800	1,900	RP0705	18,610	1,710
RC0705	.750	.200	RH	.125	7,750	950	—	—	—
R-0702	.750	.500	RH	.156	24,200	3,450	RP0702	23,855	3,150
RS0702	.750	.500	RH	.156	3,460	600	—	—	—
R-1004	1.000	.250	RH	.156	30,750	3,350	RPI004	30,415	3,015
RC1004	1.000	.250	RH	.156	12,700	1,600	—	—	—
RL1004	1.000	.250	LH	.156	30,750	3,350	RT1004	30,415	3,015
RK1004	1.000	.250	LH	.156	12,700	1,600	—	—	—
R-1002	1.000	.500	RH	.156	32,300	3,950	RP1002	31,905	3,555
R-1001	1.000	1.000	RH	.156	13,750	2,250	RP1001	13,525	2,025
RS1001	1.000	1.000	RH	.156	2,000	430	—	—	—
R-1105	1.125	.200	RH	.125	27,550	2,400	RP1105	27,310	2,160
R-1504	1.500	.250	RH	.156	47,450	4,050	RP1504	47,045	3,645
R-1502	1.500	.500	RH	.312	102,300	12,900	RP1502	101,010	11,610
RL1502	1.500	.500	LH	.312	102,300	12,900	RT1502	101,010	11,610
R-1501	1.500	1.000	RH	.344	47,800	8,250	RP1501	46,975	7,425
R-2002	2.000	.500	RH	.375	143,400	18,500	RP2002	154,635	17,235
RL2002	2.000	.500	LH	.375	143,400	18,500	RT2002	154,635	17,235
R-2001	2.000	1.000	RH	.375	134,500	21,200	RP2001	152,605	19,755
R-2202	2.250	.500	RH	.375	161,150	19,300	RP2202	159,220	17,370
R-2502	2.500	.500	RH	.375	186,000	21,200	RP2502	183,880	19,080
R-2501	2.500	1.000	RH	.375	174,000	27,000	RP2501	199,910	24,210
R-3066	3.000	.660	RH	.500	323,950	38,000	RP3066	320,150	34,200

Prefix Designations

R- = right hand thread, dual circuit*
*R-3066 is a triple circuit

RL = left hand thread, dual circuit

RC = right hand thread, single circuit

RK = left hand thread, single circuit

RQ = right hand thread, single circuit, square nut

RS = right hand thread, dual circuit, stainless steel

RP = right hand thread, dual circuit, preload

RT = left hand thread, dual circuit, preload

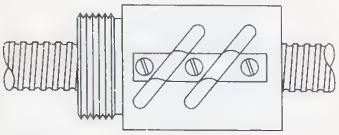
RD = right hand thread, single circuit, preload

RE = left hand thread, single circuit, preload

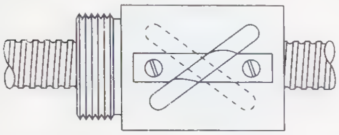
Circle 118

Series RM

- Metric leads
- 8 standard models
- Optional flanges available



Single nut, non-preload, dual circuit

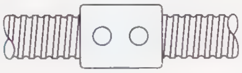


Single nut, non-preload, dual circuit

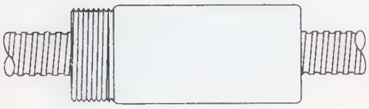
Model No.	Screw Dia. mm	Lead mm	RH LH	Nom. Ball Dia.	Maximum Static Capacity (lbs) Single Nut Non-Preloaded	Rated Dynamic Load Pounds at 1,000,000" travel Single Nut Non-Preloaded
RM1605	15.70	5	RH	.1378	11,015	1,308
RM2505	24.70	5	RH	.1378	23,379	2,355
RM2510	24.87	10	RH	.1378	30,000	3,500
RM2525	24.54	25	RH	.1560	15,000	2,500
RM4005	39.70	5	RH	.1378	37,317	3,297
RM4010	39.70	10	RH	.2812	78,230	9,445
RM5010	49.70	10	RH	.2812	109,702	12,342
RM6310	62.70	10	RH	.2812	137,352	14,398

Series M

- Industrial miniatures
- Very fine pitch leads
- Non-preload or preload available



Single nut, non-preloaded

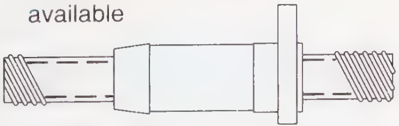


Double nut, preloaded housing

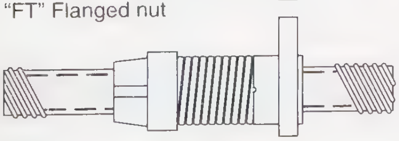
Model No.	Screw Dia.	Lead	RH LH	Nom. Ball Dia.	Maximum Static Capacity (lbs) Single Nut - non preloaded Double-nut preload	Rated Dynamic Load Pounds at 1,000,000" travel Single Nut - non preloaded Double-nut preload
M0305	.187	.050	RH	.0394	94	28
M0306	.187	.0625	RH	.0394	94	28
M0505	.312	.050	RH	.0394	162	37
M0510	.298	.100	RH	.0620	236	64

Series PN

- High helix positioning screws
- Delrin 500 CL composite nuts
- Stainless steel screws
- Zero backlash nuts available



"FT" Flanged nut



"AFT" Zero backlash flanged nut

Model No.	Screw Dia.	Lead	RH LH
PN 0310	.384	1.000	RH
PN 0312	.384	1.200	RH
PN 0408	.445	.125	RH
PN 0404	.445	.250	RH
PN 0402	.452	.500	RH

Series A

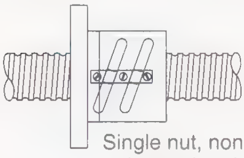
- Ball bearing splines
- 3 standard models
- Predictable life-reliable
- Smooth axial movement even while transmitting torque

Model No.	Inner Raceway Pitch	Number of Circuits	Nominal Ball Diameter	Max. static torque (in./lbs.)	Operating Load 1,000,000" travel (in./lbs.)
A-250	.625	6	.188	1,170	3,540
A-350	1.000	6	.188	2,600	7,800
A-450	1.500	6	.250	8,400	23,176

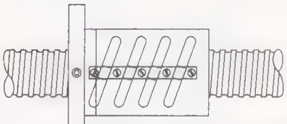
Precision Grade Ball Bearing Screws

Series GN

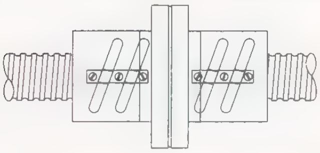
- 22 standard models
- Available in non-preload, 2 circuit and 4 circuit integral preload or double nut preload nut packages
- Integral flanges standard



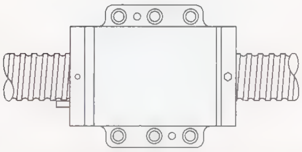
Single nut, non-preload or integral preload



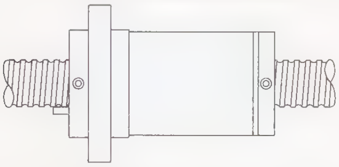
Single nut, 4-circuit integral preload



Double nut, preload, flange-to-flange



Preloaded housing for base mounting



Preloaded housing for flange mounting

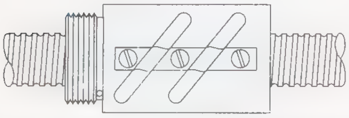
Model	Screw Dia.	Lead	RH/LH	Nom. Ball Dia.	Max.[1] Static Capacity(lbs)	Rated [1,2] Dynamic Load(lbs)
GN-0505	.500	.200	RH	.125	10,222	1,851
GN-0502	.500	.500	RH	.125	10,222	2,513
GN-0605	.598	.200	RH	.125	12,817	2,067
GN-0602	.598	.500	RH	.125	12,817	2,719
GN-0705	.750	.200	RH	.125	15,409	2,241
GN-0704	.750	.250	RH	.125	15,409	2,414
GN-1005	1.000	.200	RH	.1562	20,586	2,519
GN-1004	1.000	.250	RH	.125	25,441	3,682
GN-1205	1.250	.200	RH	.125	26,587	2,800
GN-1204	1.250	.250	RH	.1562	32,167	4,054
GN-1505	1.500	.200	RH	.125	31,762	2,986
GN-1504	1.500	.250	RH	.1562	40,185	4,462
GN-1502	1.500	.500	RH	.250	61.646	10,586
GN-2005	2.000	.200	RH	.125	42,949	3,342
GN-2004	2.000	.250	RH	.1562	53,649	4.963
GN-2002	2.000	.500	RH	.375	123,177	20,855
GN-2202	2.250	.500	RH	.375	138,715	21,958
GN-2504	2.500	.250	RH	.1562	67,109	5,380
GN-2502	2.500	.500	RH	.375	154,245	22,948
GN-3002	3.000	.500	RH	.375	202,204	26,587
GN-3066	3.000	.660	RH	.500	258,800	42,570
GN-3001	3.000	1.000	RH	.500	258,800	48,722

[1] Static and dynamic ratings are for single nut non-preloaded, double nut preloaded and 4-circuit preloaded nut configurations. Single nut preloaded ratings are approx. 40% lower.

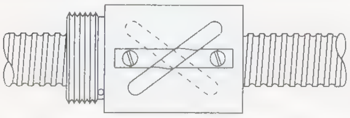
[2] Dynamic load ratings are for 1,000,000 of travel.

Series GV

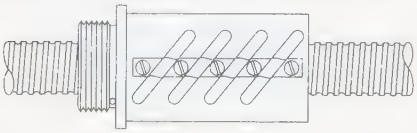
- 14 standard models
- 5 all new models
- Maximum mounting flexibility
- Optional flanges



Single nut, non-preload or integral preload



Single nut, non-preload or integral preload



Single nut, 4-circuit non-preload or integral preload

Model	Screw Dia.	Lead	RH/LH	Nom. Ball Dia.	Max.[1] Static Capacity(lbs)	Rated [1,2] Dynamic Load(lbs)
GV-0502	.500	.500	RH	.125	9,883	2,429
GV-0605	.598	.200	RH	.125	7,762	1,998
GV-0602	.598	.500	RH	.125	7,372	2,597
GV-0705	.750	.200	RH	.125	19,897	2,894
GV-1005	1.000	.200	RH	.125	15,812	1,933
GV-1004	1.000	.250	RH	.1562	19,531	2,513
GV-1004	1.000	.250	LH	.1562	19,531	2,513
GV-1205	1.250	.200	RH	.125	34,332	3,617
GV-1505	1.500	.200	RH	.125	55,738	5,239
GV-1504	1.500	.250	RH	.1562	23,098	6,904
GV-1502	1.500	.500	RH	.250	59,602	10,235
GV-1501	1.500	1.000	RH	.3437	81,275	19,700
GV-2202	2.250	.500	RH	.375	179,119	28,354
GV-2201	2.250	1.000	RH	.375	179,119	35,724

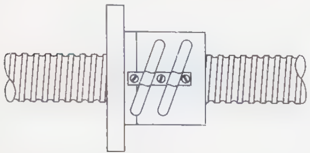
[1] Static and dynamic ratings are for single nut non-preloaded and double nut preloaded nut configutation. Single nut preloaded ratings are approx. 40% lower.

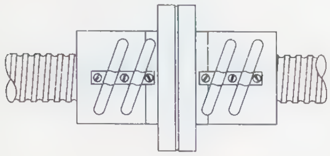
[2] Dynamic load ratings are for 1,000,000 of travel.

Circle 118

Series MM

- 8 standard models
- Metric leads
- Non-preload or preloaded


Single nut, non-preload or integral preload


Double nut, preload, flange-to-flange

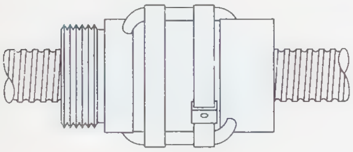
Model	Screw Dia.	Lead	RH/LH	Nom. Ball Dia.	Max.[1] Static Capacity(lbs)	Rated [1,2] Dynamic Load(lbs)
MM 20-5	19.05	5mm	RH	.125	15,409	2,230
MM 25-5	25.40	5mm	RH	.125	20,586	2,506
MM 32-5	31.75	5mm	RH	.125	26,587	2,787
MM 40-5	38.10	5mm	RH	.125	31,762	2,970
MM 40-10	38.10	10mm	RH	.156	26,469	3,420
MM 50-5	50.80	5mm	RH	.125	42,949	3,325
MM 50-10	50.80	10mm	RH	.250	85,745	11,292
MM 63-10	63.55	10mm	RH	.250	106,485	12,231

[1] Static and dynamic ratings are for single nut non-preloaded and double nut preloaded nut configutation. Single nut preloaded ratings are approx. 40% lower.

[2] Dynamic load ratings are for 1,000,000 of travel.

Series RB

- 22 standard models
- High lead/fast lead
- Preload and non-preload nuts
- Maximum mounting flexibility
- Optional flanges

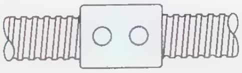

Single nut, non-preloaded or integral preload

Model	Screw Dia.	Lead	RH/LH	Nom Ball. Dia.	# of Starts	# of Turns/ Start	Integral Preload	Max. Static Capacity(lbs)	Rated* Dynamic Load(lbs)
RB-0701A	.750	1.000	RH	.125	2	1.5	No	5,282	1,862
RB-0701B	.750	1.000	RH	.125	2	1.5	Yes	3,201	1,024
RB-0702A	.750	.500	RH	.1562	2	2.5	No	9,957	3,018
RB-0702B	.750	.500	RH	.1562	2	2.5	Ys	6,034	1,660
RB-0720A	.750	2.000	RH	.1562	4	.67	No	5,800	2,790
RB-0720C	.750	2.000	RH	.1562	4	.67	Yes	3,210	1,543
RB-1001A	1.000	1.000	RH	.1562	2	1.5	No	8,722	2,846
RB-1001B	1.000	1.000	RH	.1562	2	1.5	Yes	5,285	1,565
RB-1020A	1.000	2.000	RH	.1562	4	.67	No	7,882	3,241
RB-1020C	1.000	2.000	RH	.1562	4	.67	Yes	4,362	1,793
RB-1520E	1.500	2.000	RH	.1875	4	1.67	No	31,555	10,978
RB-1520F	1.500	2.000	RH	.1875	2	1.67	No	17,415	6,058
RB-1520G	1.500	2.000	RH	.1875	4	1.67	Yes	17,415	6,058
RB-1520H	1.500	2.000	RH	.1875	2	1.67	Yes	9,580	3,333
RB-2001A	2.000	1.000	RH	.1562	4	1.67	No	36,548	7,785
RB-2001B	2.000	1.000	RH	.1562	2	1.67	No	20,170	4,296
RB-2001C	2.000	1.000	RH	.1562	4	1.67	Yes	20,170	4,296
RB-2001D	2.000	1.000	RH	.1562	2	1.67	Yes	11,113	2,367
RB-2020E	2.000	2.000	RH	.1875	4	1.67	No	43,500	12,595
RB-2020F	2.000	2.000	RH	.1875	2	1.67	No	23,953	6,950
RB-2020G	2.000	2.000	RH	.1875	4	1.67	Yes	23,953	6,950
RB-2020H	2.000	2.000	RH	.1875	2	1.67	Yes	13,177	3,823

*At 1,000,000 of travel.

Series P

- Precision miniatures
- Very fine pitch leads
- Non-preload or preloaded


Single nut, non-preloaded

Double nut, preloaded housing

Model	Screw Dia.	Lead	RH/LH	Nom. Ball Dia.	Max.* Static Capacity(lbs)	Rated* Dynamic Load(lbs)
P0405	.250	.050	RH	.0393	170	15
P0410	.250	.100	RH	.0393	170	18
P0610	.375	.100	RH	.0625	370	39
P0805	.500	.050	RH	.0393	370	22
P0810	.500	.100	RH	.0625	530	46
P1210	1.000	.100	RH	.0620	800	59

* Static and dynamic ratings are for single nut non-preloaded and double nut preloaded nut configurations. Dynamic load ratings are for 1,000,000 of travel.

AT both use 16-bit data paths. The original clock speed of the PC is 4.7 MHz, but some AT clones now provide clocks of up to 12 MHz and even higher.

It now seems that the AT bus may be enhanced through use of a separate 32-bit memory bus. One manufacturer uses this scheme in desktop machines that employ an AT bus along with the 80386 32-bit processor. Manufacturers of PC-compatible machines have developed a specification called EISA that calls out a similar bus scheme.

The latest PS/2 machines use a bus architecture that is incompatible with previous PCs or high-end systems. The Micro Channel Architecture (MCA) handles up to 16M bytes of address space. MCA uses a complex bus arbitration to allow several competing devices on the bus to share the address, data, and control lines without conflict.

Under normal circumstances, the processor uses the Micro Channel for memory and I/O accesses, supplying address values and synchronizing control signals. Another interesting feature is that PS/2 I/O devices have a full 16-bit address, instead of the 10-bit address used in PCs, to produce 64k addresses.

The recently introduced Macintosh II workstations use yet another standard called NuBus and are the first major machines to do so. NuBus supports 8, 16, and 32-bit data transfers and a peak data-transfer rate of 37.5M bytes/s. The bus allows data interchanges between devices within a 4G-byte address space.

The S-100 bus started out as an interconnection standard for hobby computers and is now used in some industrial applications. This interconnection scheme was refined by an international standards committee into a standard now called the IEEE-P696. However, many experts feel that this standard is not defined well enough for high-performance microcomputer products.

The IEEE 488-bus standard is commonly used in computer control of test instruments. Another standard, the STD bus, uses smaller 4.5 × 6.5-in. boards. In terms of computing performance, STD and PC-bus processors are often comparable. Physical size of the cards is also similar. Frequently used peripherals such as floppy and hard disks are also available for both formats, and both can be configured to run MS DOS software.

Because of these similarities, either format can be found powering industrial equipment such as NC milling machines or injection-molding machines. But manufacturers that supply both kinds of cards say that a need for high reliability or operation in particularly harsh environments can dictate the use of STD cards.

For example, where some PC-bus cards (particularly made in the Far East) carry a 90-day warranty at most, STD bus cards performing the same functions can be had with a five-year warranty. Many of these same cards operate over an industrial temperature range of 0 to 65°C. Few PC bus cards, in contrast, are rated for this temperature.

STD cards also have a reputation for ruggedness. They tend to be used in embedded applications where the machine under control cannot be down for long.

STD excels in number and type of I/O cards offered as well. Although the number of I/O cards for the PC is increasing, boards in this format have generally been limited to laboratory monitoring functions for transducers such as thermocouples, or relay cards for on/off controls.

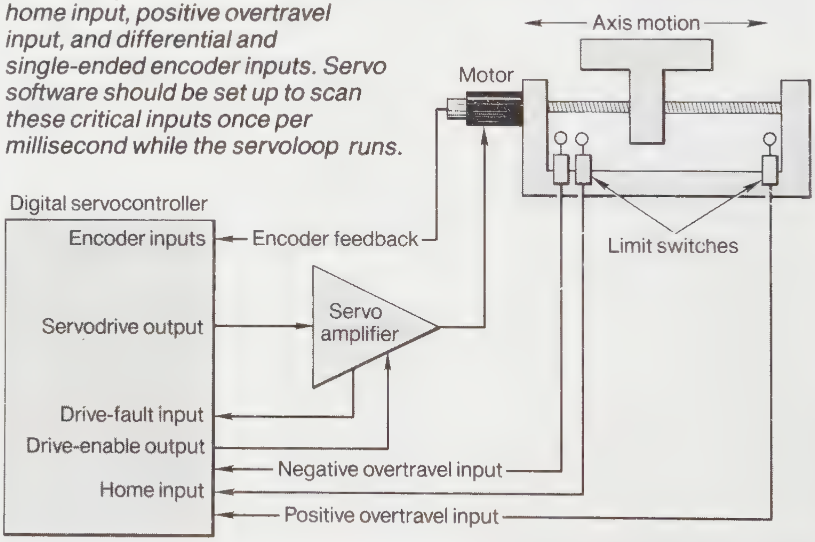
In contrast, a wide range of industrial I/O boards are available for STD. One reason, say manufacturers, is that designing for the STD backplane is straightforward, so much so that 30% of all STD boards are in-house designs developed by end users. This ease further promotes I/O board availability because numerous STD I/O boards are first developed for specific end uses, then commercialized.

The penalty paid to use the STD format is slightly higher prices and incompatibility with PC software. A number of suppliers now provide STD boards that are file compatible with MS DOSs. But, as with some PC clones, software that bypasses the operating system to directly manipulate hardware frequently causes problems.

Dedicated boards

A number of commercially available board-level computers are targeted specifically at servocontrol. These devices might take inputs from a control panel or a host computer. For example, many dedicated controllers today consist of cards that reside in industrially hardened PCs, or in VMEbus card cages. They take high-level positioning commands such as *move the slide 10 inches* from computers on other cards.

When evaluating servocontroller boards, an important factor to determine is whether the boards provide special I/O normally used in motion control, as depicted here. Typical of such I/O is a drive-fault input, drive-enable output, negative overtravel input, home input, positive overtravel input, and differential and single-ended encoder inputs. Servo software should be set up to scan these critical inputs once per millisecond while the servoloop runs.

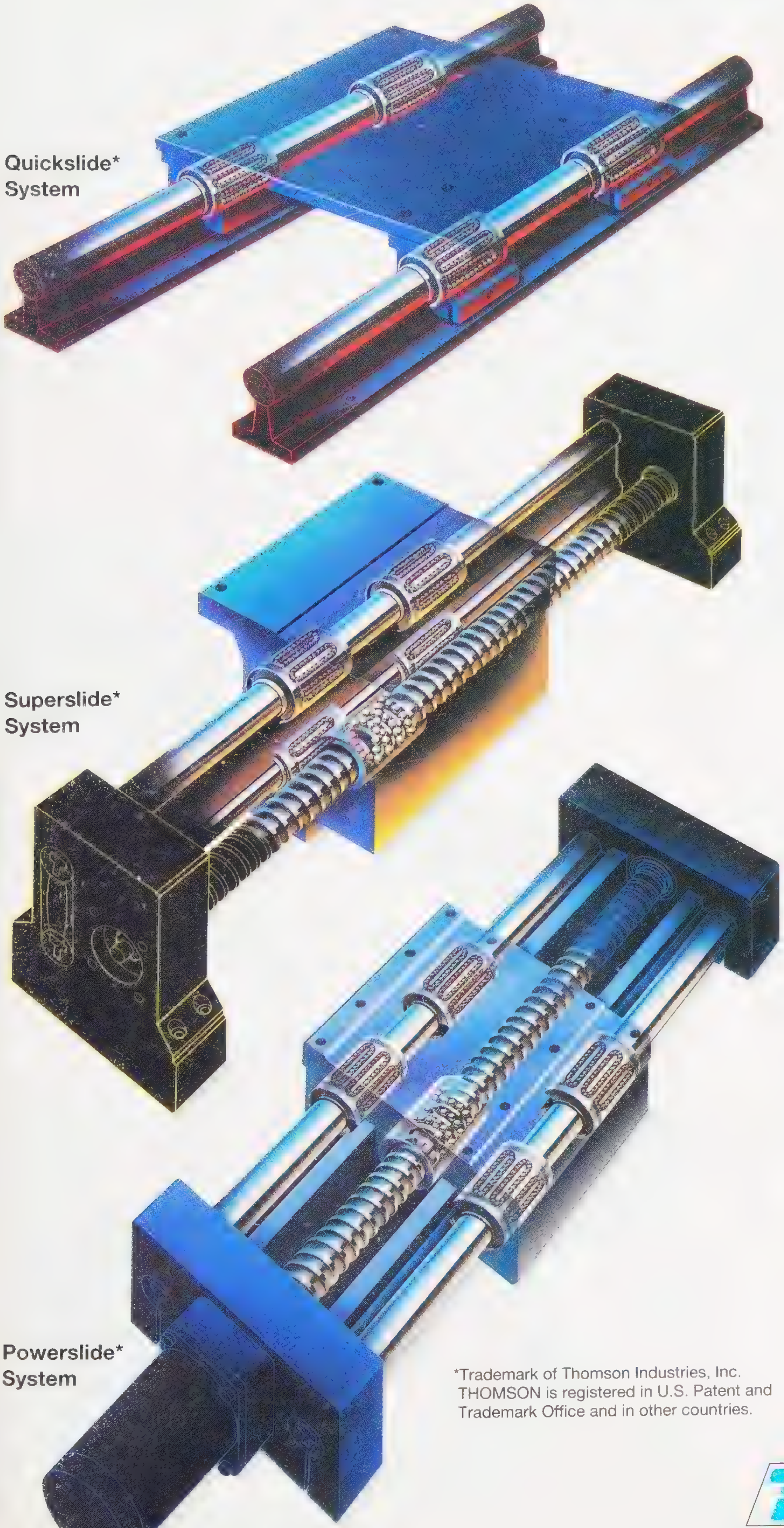


These servocontroller systems also provide dedicated interface hardware to accept and process position-encoder feedback signals and to generate drive signals for a servoamplifier. Finally, they run software that closes a feedback loop and stabilizes the system.

Any digital servocontroller must be able to operate reliably in the electrically noisy industrial environment. Noise immunity must go beyond mere shielding, bypassing, and even optical coupling. The controller must be designed to fail gracefully in the event that noise somehow garbles signals. However, not all controllers provide such safeguards.

Three types of input/output signals must be protected from noise interfer-

Put Our 47 Years of Technological Leadership to Work for You



Thomson Industries has long been recognized as the leader in linear motion products and applications. From the invention of the revolutionary Ball Bushing* linear bearing in 1944, Thomson continues to lead the industry it created.

Today, we offer pre-engineered, pre-assembled, ready-to-install linear motion Systems, made from time-proven Thomson components. They feature load capacities up to 6200 lbs., travel speeds up to 10 ft./sec., and unlimited travel lengths. You can order Systems in fully supported, end supported and unsupported configurations. No matter which you choose, Thomson Systems save you hours of design and assembly time. They arrive at your factory ready to go to work.

We still offer components:

- Super Ball Bushing* bearings
- 60 Case* shafts
- Pillow blocks
- Thomson Saginaw* ball screws
- Performance Pak* electro-mechanical actuators
- Precision balls in metal or ceramic.

For a free copy of the Thomson Advanced Linear Motion Systems catalog, and the name of your nearest distributor, call 1-800-645-9357; Fax 1-516-883-9039; or write to Thomson Industries, Inc., Port Washington, NY 11050.

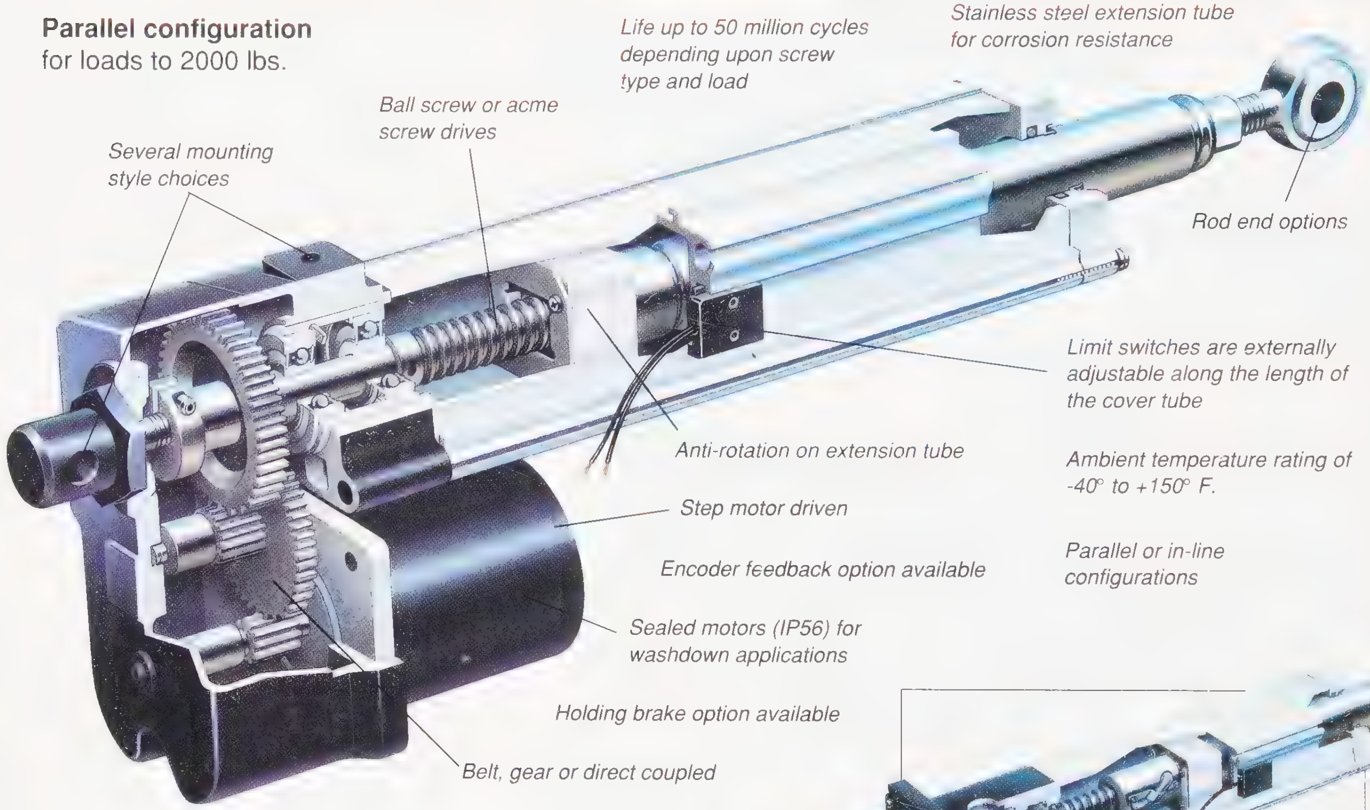
*Trademark of Thomson Industries, Inc. THOMSON is registered in U.S. Patent and Trademark Office and in other countries.

THOMSON
INDUSTRIES, INC.
Thomson Job Hotline 1-800-26-APPLY

Circle 125

WARNER/SUPERIOR Electrak® 2000 Programmable Actuator Systems...

Parallel configuration
for loads to 2000 lbs.


Life up to 50 million cycles depending upon screw type and load
Stainless steel extension tube for corrosion resistance
Ball screw or acme screw drives
Several mounting style choices
Rod end options
Limit switches are externally adjustable along the length of the cover tube
Anti-rotation on extension tube
Ambient temperature rating of -40° to +150° F.
Step motor driven
Encoder feedback option available
Parallel or in-line configurations
Sealed motors (IP56) for washdown applications
Holding brake option available
Belt, gear or direct coupled

Step motor driven actuators for accurate, repeatable positioning. Complete, easy-to-use programmable indexer controls.

The Electrak 2000 actuator offers a wide choice of features, from highly efficient ball bearing screw drives for high speed, high load and 100% duty cycle, to self-locking acme screws for prevention of backdriving loads. Parallel or in-line configurations provide different package sizes along with five mounting options and three rod end styles for customizing to your application.

- Load ratings to 2000 lbs.
- Repeatability to 0.0005"
- Stroke lengths to 24"
- Speeds to 20" per second
- Life to 50 million cycles.

Programmable Indexers

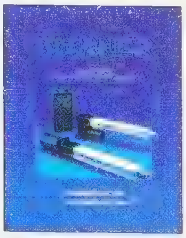
- Provides absolute or incremental control of position
- Store up to 400 program lines in nonvolatile memory
- Simple, easy-to-use programming format
- Full, half-step and micro step operation
- Short circuit protection.

In-line configuration
For space restricted applications, loads to 500 lbs.

Programmable controls for maximum application flexibility.

The Electrak 2000 programmable actuator system is available through a nationwide network of more than 500 **Warner Electric** and **Superior Electric** distributor outlets.

Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog P-1023
815/389-3771
Fax 815/389-2582



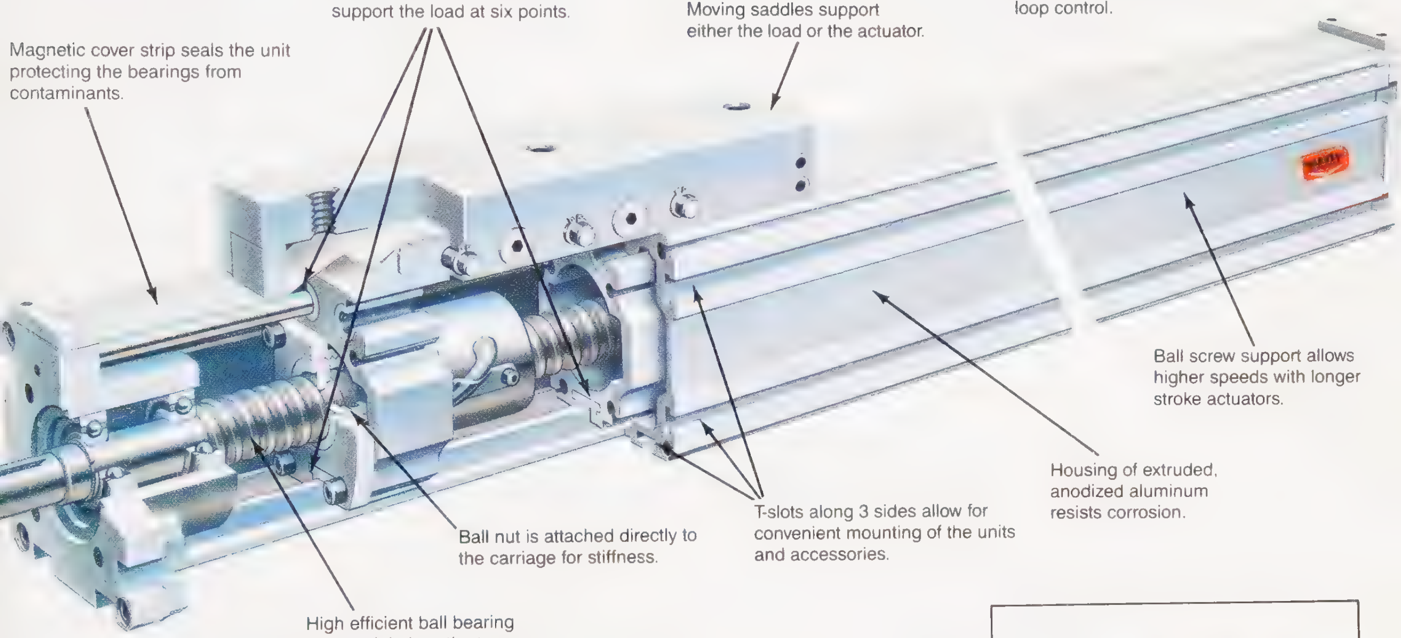
WARNER ELECTRIC

DANA

Circle 696

WARNER ELECTRIC
Rapidtrak® linear actuators…

High speed, long stroke lengths, modular designs, accepts a wide range of prime movers



New!
Stroke lengths to 22 feet

Magnetic cover strip seals the unit protecting the bearings from contaminants.

Sturdy Robalon bearings support the load at six points.

Moving saddles support either the load or the actuator.

An optional flange allows an encoder to be attached directly to the ball screw for closed loop control.

Ball screw support allows higher speeds with longer stroke actuators.

Housing of extruded, anodized aluminum resists corrosion.

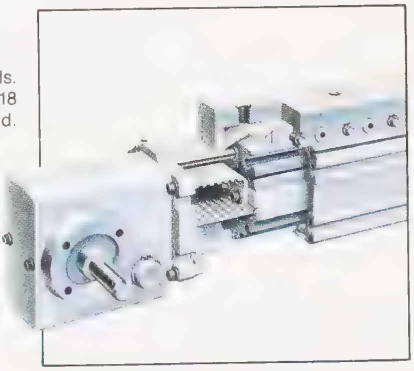
T-slots along 3 sides allow for convenient mounting of the units and accessories.

Ball nut is attached directly to the carriage for stiffness.

High efficient ball bearing screw minimizes the torque needed to drive the load.

Standard flange for NEMA 56C or gearboxes. Optional flange for custom motors, reducers, servos, or step motors.

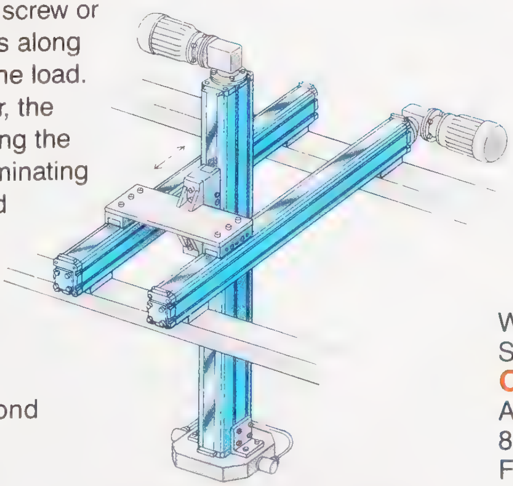
Belt drive for light loads and high speeds. Thrust loads to 281 lbs. and speeds to 118 inches per second.



A unique concept in linear motion control…

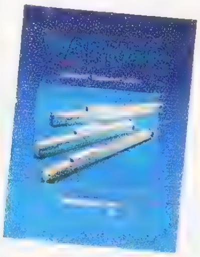
The Rapidtrak linear actuator provides guided linear motion using either a ball screw or belt drive and a saddle that rides along the top of the actuator to carry the load. Unlike a typical rod type cylinder, the Rapidtrak concept permits placing the load directly on the actuator, eliminating the need for external guides and ways. It also provides a more compact package as the extended and retracted lengths are the same.

- Stroke lengths to 22 feet
- Speeds up to 118″ per second
- Thrust loads up to 900 lbs.
- Can be mounted horizontally, vertically or upside down.
- Accepts wide range of prime movers — AC, DC, servo, air, hydraulic or step motor.



Rapidtrak actuators are easily combined for load sharing or multi-axis applications.

Our customers are served promptly through a nationwide network of more than 500 distributor outlets.



Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog P-958
815/389-3771
Fax 815/389-2582

WARNER ELECTRIC

DANA

Circle 126

A control engineer's checklist

10 Good Reasons Why You Should Check Out Your Motion Control Supplier

1 ☑ How's the manufacturer's track record?

Years of experience count for a lot. The more systems they have out there, and the more applications they've handled, the more likely it is that they can solve your particular problems. And you should be able to ask for—and get—a pretty long list of current customers.

2 ☑ Do they offer what you need?

Just having a big selection of products doesn't count for much if they don't have any that are specific to your problem. And having the right product means you don't have to underbuy and take a chance. Or overbuy and waste your money.

3 ☑ Are their products up to date?

Technology is changing fast. Good manufacturers strike a balance between the totally new and the recently proven. The technology should be leading edge. Not over the edge.

4 ☑ A little testing might be in order.

Don't be a guinea pig for products with unproven reliability. Find out how many of those systems are out there running right now. And how well. Given a choice, you probably don't want Serial No. 1 untested.

5 ☑ Can their products be upgraded to take advantage of the latest technology?

That big investment you made today might be obsolescent by next Wednesday. Controllers and other system components that can be easily upgraded to use new technology can deliver increased performance with minimum rework.

6 ☑ Make sure the controllers you bought years ago talk to the ones you buy tomorrow.

You want your employees to speak the same language. Does it make any sense to have a bunch of controllers that don't? And programs that are transportable from one system to another can save you a lot of time. And money.

7 ☑ Service with a smile? Or a grimace?

You can always get service if you scream loud enough. The point is that you shouldn't have to scream at all. Service should be quick, efficient, complete. And delivered by people who have an intimate knowledge of their systems and capabilities, because they regularly use their own products.

8 ☑ Educational support would be nice.

How your system performs depends a lot on how well you know how to operate it. Training should be available at your place or theirs. Manuals should be complete, current, easy to understand. And you should have a friend at the other end of your phone if you have a question.

9 ☑ Pieces and parts vs. standardized systems.

Don't be stuck trying to integrate a lot of miscellaneous hardware. The manufacturer should have already done it for you. Components should just plug in and go to work. The lack of standardization in the industry is his problem. Don't let him make it yours.

10 ☑ A really good warranty is a really good check on the products and the company.

Companies can only afford to offer great warranties on equally great products. Anything less can get very expensive in a hurry. And the warranty should be based on system level operating characteristics, not just pieces and parts. You're buying functions and specs. Make sure that's what's guaranteed.

☑ ☑ ☑ ☑ ☑ ☑ ☑ ☑ ☑ ☑

Industrial Indexing Systems checks out. We've been in the motion control business quite a while. And we expect to stay in business quite a while longer. We have thousands of systems out there right now. Most of those systems can talk to each other. Most of them use a transportable language. Many of them can be upgraded with newer technology. And all of them were designed as systems, installed as systems. And fully warranted as systems under our Guaranteed System Performance program.

And we have countless customers out there. Customers who, almost without exception, like our products, our service, our training and—most of all—our attitude. Before those people wrote their big check, they did a few smaller ones.

You should too. Give us a call. We're IIS. And we check out.

IIS

Industrial Indexing Systems
626 Fishers Run, Victor, NY 14564
Telephone (716) 924-4470

© Industrial Indexing Systems, 1991

ence: encoder inputs, servodrive output, and any discrete I/O that the digital servocontroller provides. Feedback encoder signals are particularly sensitive to noise. Corruption of these signals can cause position inaccuracies, jerky or rough operation, and even dangerous unexpected motion.

One way to minimize such noise effects is through the use of differential encoders. Here, each encoder channel signal is transmitted to the digital servocontroller over two wires. Position information is transmitted as the difference between the two signals levels rather than as a voltage level referenced to ground.

Not all digital servocontroller boards can accept differential encoder inputs, however. Nor do all boards capable of servocontrol use optically isolated inputs. In general, less-expensive boards do not provide such isolation. These products are best suited for laboratory and light industrial use.

The servocontroller typically provides a ±10-V output to the servodrive. These signals are more difficult to optically isolate than the relatively small encoder signals. In some cases, digital servocontrollers use a conventional digital-to-analog converter (DAC) to provide an output voltage. In this case, an analog isolation amplifier may be used on the DAC output, or separate optocouplers can handle each of the input bits. Usually, however, both these isolation techniques are prohibitively expensive.

Isolation is less expensive when the servocontroller generates a high-frequency PWM signal. A PWM output can be easily isolated with conventional optocouplers. The resulting isolated output can then be converted to the required ±10-V signal needed to drive motors.

To maintain the integrity of the optical isolation, an isolated ±12 to ±15-V supply must power the circuitry between the PWM output of the controller and the ±10-V output to the motor. In most cases, the servoamplifier itself provides these voltages, without the need for a separate supply.

It is standard industrial practice to optically isolate all discrete inputs and outputs. A complete digital servocontroller for industrial applications must not only provide discrete I/O for motion-related functions, but should also incorporate on-board optical isolation for protection from switching transients and fault voltages.

Industrial I/O usually operates at either 120 Vac or 24 Vdc. Many applications use both. But digital servocontrollers should provide only 24 Vdc to ensure that 120-V line voltages are kept away from sensitive microprocessor circuitry.

In general, servocontrollers must handle a few discrete inputs and outputs having functions intimately tied to the control of axis motion. These I/O include the home limit switch and encoder marker, axis-overtravel switches, drive-fault input, and drive-enable output. For best performance, the servocontroller should handle these motion-specific I/O directly, but not all controllers provide for such specialized I/O.

Because position-feedback encoders are typically incremental, a servocontroller must be able to find a known absolute home position to calibrate its motion. This calibration uses both a home limit switch and the marker channel on the encoder. Thus, the servocontroller must handle the encoder marker and home limit-switch inputs.

The encoder marker is a third output from the incremental encoder that indicates a single, unique position of the encoder. In some applications, the encoder marker alone provides enough information to establish a unique reference position for axis calibration.

New SLO-SYN® Enhanced Motion Controls

...with closed loop option and advanced operating features.

New SLO-SYN® Enhanced Motion Controls are available for half- or full-step, 1/10 or 1/125 microstep operation of SLO-SYN® DC Stepper Motors. Both open and closed loop indexer models are offered in preset (single line) and programmable (400 line) types for added versatility and improved performance. Features include:

- ***Smoother acceleration and deceleration***
- ***Selectable ramp profiles***
- ***Additional I/O capabilities***
- ***Velocity changes during motion***
- ***Programmable backlash compensation***
- ***Index from run***

For full information, write, fax or phone for SLO-SYN® Enhanced Motion Control Catalog MSCS191.

Call ***1-800-447-7171*** *today.*

Superior Electric

DANA

MADE IN USA

Bristol, CT 06010 / (203) 582-9561
FAX: (203) 589-2136 / TLX: 96-2446

Circle 128

Applications in this category include rotary indexing tables or machines using linear encoders. Usually, however, the encoder completes many revolutions within the travel range of the axis, so the encoder marker alone is not enough to define a unique reference position.

A home limit switch activates at only one place in the total travel of the axis. This switch can be mechanical, optical, magnetic, Hall effect, and so forth. By first searching for the home limit-switch signal and then for the encoder marker signal, the digital servocontroller can home the axis and quickly establish a precise reference position over a large range of travel.

Overtravel switches are employed to prevent a programming error or fault condition from damaging the axis mechanics. The axis activates these switches when it reaches its defined travel limits. The digital servocontroller can inhibit axis motion to prevent machine damage when it senses the overtravel switch closure.

Most servoamplifiers provide an output that activates when a fault within the amplifier takes place. Obviously, if the servoamplifier malfunctions, the digital servocontroller cannot control the axis and must inhibit further motion until the fault clears. Thus, the controller should provide a drive-fault input to handle the drive-fault output from the servodrive.

Most servoamplifiers also provide a drive-enable input. Servocontrollers can use this input to enable and disable the amplifier to avoid unexpected motion during system start-up and shutdown. In addition, the servoamplifier should be disabled immediately whenever the servocontroller detects a fault. The controller, thus, should provide a drive-enable output to allow for enabling and disabling the servoamplifier.

Besides monitoring and reacting to discrete sensor signals that warn of external faults, the servocontroller must monitor its own internal conditions and take action if those conditions could cause damage.

Some fail-safe measures have become standard on industrially hardened computers. For example, many such devices incorporate a watchdog timer circuit. This circuit controls a relay contact that can cut power to the machine. A typical watchdog time-out event might consist of a loss of the encoder-feedback signal, or some other condition that could occur if the machine was moving out of control.

Another kind of watchdog circuit shuts down the machine if the controller ceases to operate. One way to implement this function is with a circuit that only stays activated as long as it receives a periodic signal from the servocontroller. The hard-contact output of the circuit is generally incorporated into the machine emergency-stop circuit or other safety shutoff.

If the servoamplifier fails, it activates a drive-fault input to the digital servocontroller. The controller should then take action to minimize the effect of the fault. Normally, this action might consist of stopping axis motion, disabling feedback, and notifying the operator or host control system. Of course, when the fault in the drive system clears, the servocontroller must also be able to reestablish control without unexpected axis motion. As long as power to the encoder is present, the servocontroller should also be capable of resuming operation without reestablishing the home position.

When the axis exceeds maximum travel, severe damage can result. Limit switches are usually employed to alert the servocontroller of impending overtravel. In addition, the actual position of the axis reported by the encoder can be continuously compared to prede-

New SLO-SYN® Preset Indexer Model SP-255

...addresses a multitude of simple, repetitive motion control applications.

- ***All motion parameters are programmable by switches on the front panel***
- ***Index distance can also be selected from remote switches***
- ***Single step and jog operation are provided for manual setup***
- ***Built-in bipolar chopper drive operates SLO-SYN® Stepper Motors in full/half step***
- ***Motor current from 0.5 to 3 amperes selectable from front panel***
- ***All inputs and outputs are optically isolated, single point, terminal strip connections***
- ***Pulse and direction can be provided to a second drive allowing two axes to follow specified parameters***
- ***Inputs are sink and source compatible***

Write, fax or phone for full information in SLO-SYN® Preset Indexer Model SP-255 Bulletin SP255-691 and Motion Control Tech-Pak.

Call ***1-800-447-7171*** *today.*

Superior Electric

DANA

MADE IN USA

Bristol, CT 06010 / (203) 582-9561
FAX: (203) 589-2136 / TLX: 96-2446

Circle 129

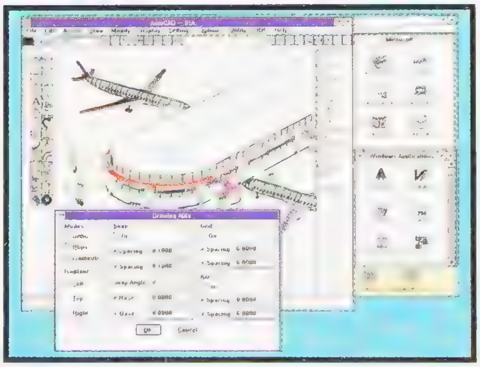
"You

We have to admit, you're persistent. Year after year, you've had the same objections to learning CAD. So we've finally decided to do something about them.

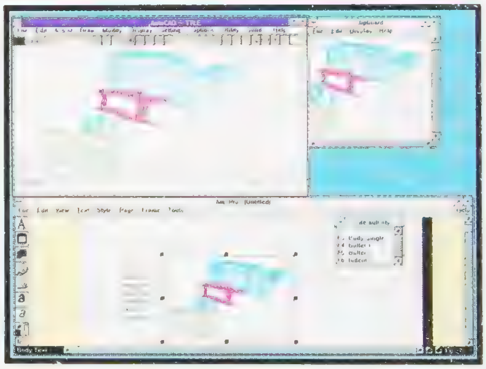
Objection #1:

"IT TAKES TOO LONG TO LEARN."

Not any more. Now AutoCAD® runs on Windows.™ That means you get all the advantages of AutoCAD without memorizing command names. Instead, you create your drawings by selecting simple Windows tools and icons. So your learning curve is much shorter.



The intuitive Windows interface, tools and icons make AutoCAD far more accessible



With the Windows clipboard, AutoCAD drawings are easily added to documents and presentations created on desktop publishing, paint, drawing or word-processing software.

Now AutoCA

Objection #2:

"I CAN'T DESIGN ON A COMPUTER."

Windows helps change all that. Its intuitive interface and pull-down menus eliminate most of the repetitive keyboarding that makes computer work feel confining.

The AutoCAD Release 11 Extension for Windows also lets you move back and forth effortlessly between other Windows applications. So you can work the way that comes naturally to you. Create a brilliant drawing on AutoCAD. Write the specs on your word-processor. Then use the Windows Clipboard to insert both pieces into a desktop publishing program, so you can polish your proposal.

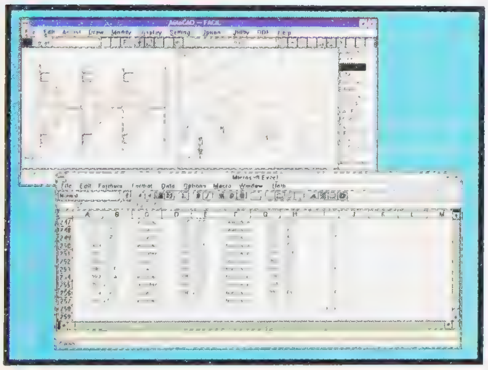
Objection #3:

"I CAN WORK FASTER BY HAND."

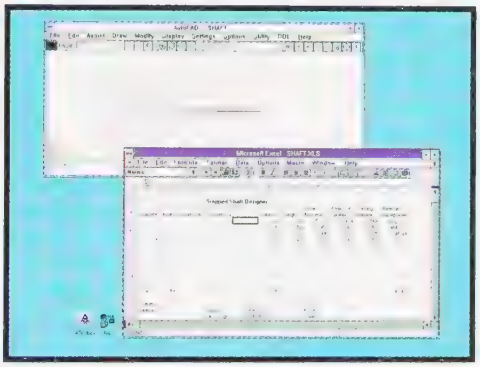
Okay, let's be honest about this. Maybe you and your pencil can beat the blazing speed of AutoCAD for rough sketching. But AutoCAD leaves your pencil in the dust

*Suggested retail price. Autodesk, the Autodesk logo and AutoCAD are registered trademarks of Autodesk, Inc. All other trademarks are trademarks of their respective holders

Win.”



Using Dynamic Data Exchange, you can eliminate many repetitive tasks by linking AutoCAD to other Windows programs.



AutoCAD gives you the tools to link your drawings to spreadsheets. So you can explore the possibilities of parametric design.

uns On Windows.

when it comes to designing, making revisions and creating multiple views.

That's not all. AutoCAD on Windows has another way to make you more productive. It's called Dynamic Data Exchange (DDE). With DDE, information flows in both directions between AutoCAD and other Windows applications, like Microsoft® Excel® and Lotus 1-2-3.®

So when you update an AutoCAD drawing, new costs can be automatically computed on your spreadsheet. And when you update your spreadsheet, it can revise your AutoCAD drawing for you. See how long that takes you by hand.

With the new AutoCAD Extension for Windows, all the advantages AutoCAD users have been hoarding are now accessible to you. Now your files will be instantly transferable, and your work compatible with more than 650,000 other AutoCAD users. That probably includes many of your clients and colleagues. In addition, you can use the power of programs like Microsoft Visual Basic™ or Borland Turbo C++™ to create custom CAD applications that fit the work you do.

Only $99 for AutoCAD Release 11 Users.*

Still on the fence? Call 1-800-445-5415 ext. 523 for the name of the nearest Authorized AutoCAD Dealer.

AUTODESK®

Circle 130

fined maximum travel values to provide secondary overtravel protection. This secondary protection is generally called software travel limits. Software travel limits can be used with or in place of overtravel limit switches.

When used for overtravel protection, a software travel limit is usually considered a fatal fault. As in the case of hitting hardware limit switches, the controller stops any motion on the axis, disables the software-feedback loops and the drive, and advises the host of the problem.

The limit-switch placement should allow sufficient deceleration distance between the software travel limits and the overtravel limit switches. Otherwise, the system may not have enough space to stop without tripping an overtravel limit switch.

The tripping of an overtravel limit switch is always interpreted as a fatal fault. Here, the servocontroller must again shut down the machine. Enough travel distance must be provided beyond the overtravel limit switch for the axis to come to a complete stop without damaging the machine mechanics.

Servo following error is the axis-position error, or the difference between the commanded and actual positions, when the axis is moving. The digital servocontroller should monitor the servo following error and constantly compare it to the preset following error tolerance value. If the tolerance value is ever exceeded, the controller must stop all axis motion, disable feedback and the servoamplifier, and notify the operator.

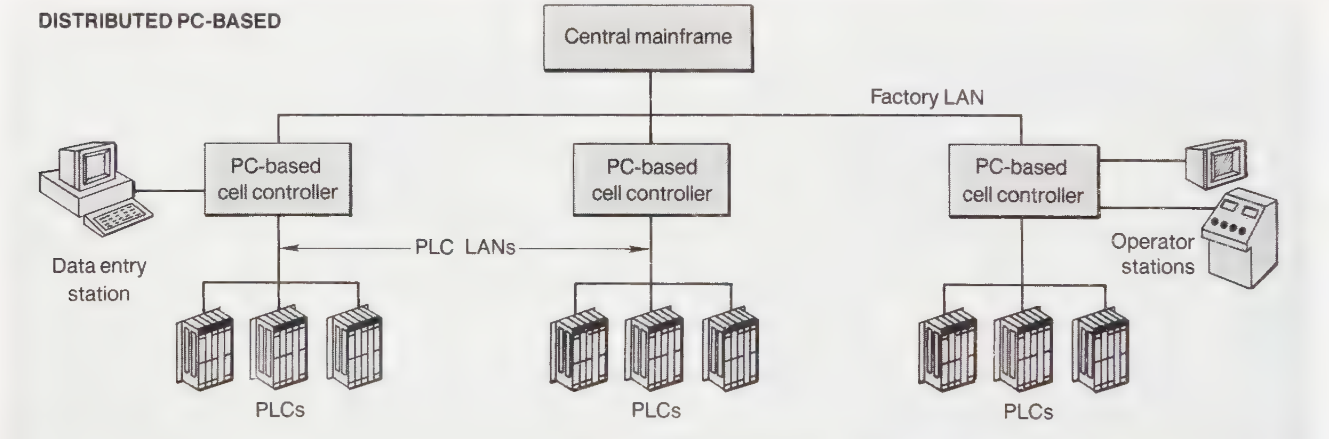
Cell controllers

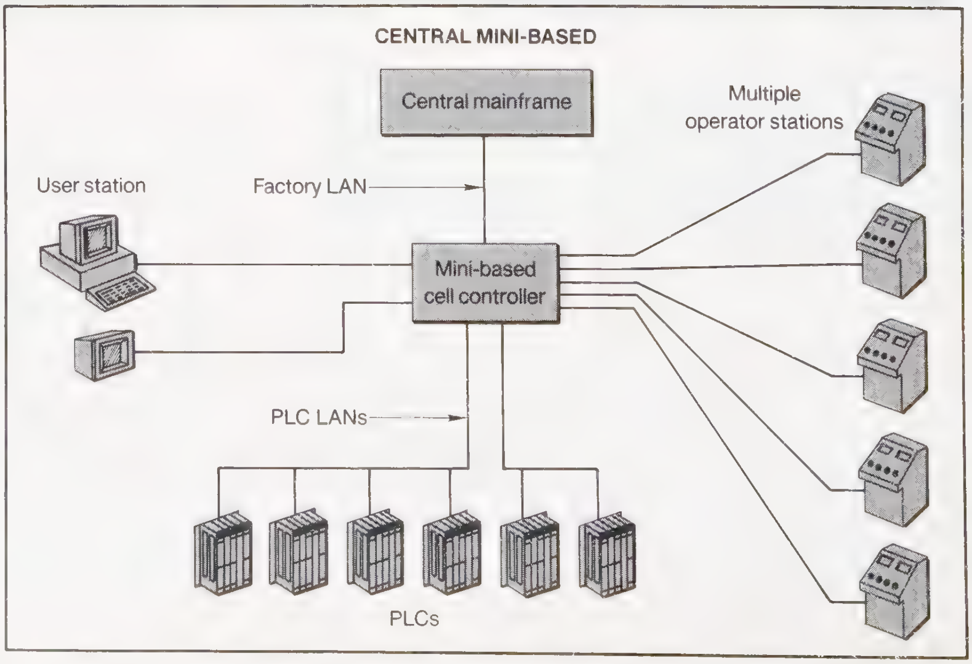
In some factories, computers called cell controllers provide coordination among individual workstations and computer-controlled machines. Their duties also may involve supervision of motion controllers, or the collection of manufacturing statistics from such machines.

There is no formal definition of what cell control actually is. A few years ago, most people thought of a cell controller as an all-encompassing computer that watched over an entire plant. Today, a cell controller is often just a small, rugged computer, linked to several PLCs, which doubles as an operator station. This computer frequently downloads different programs to PLCs from its hard disk, eliminating the collections of Mylar tapes normally used to reconfigure processes or assembly lines. It may also act as an information filter that passes manufacturing statistics up to a mainframe. Estimates are that computers based on a PC-compatible format account for the vast majority of cell-controller installations.

Different industries use such controllers for diverse purposes. Suppliers say, for example, that controllers installed in automotive plants generally collect diagnostic information, track parts through assembly lines, and collect quality information in processes such as welding or metal cutting. These data often are used for statistical process-control calculations that are fed back to a larger central computer.

On the other hand, cell controllers in stamping plants and food-processing





Suppliers often say that PC-based cell controller installations take a distributed approach. Though there are exceptions, a PC-based controller generally handles one or two PLC networks at most, and one operator station. In contrast, cell controllers based on minicomputers provide more of a centralized approach. Such controllers may handle four or more PLC networks, as well as multiple operator stations. In both the distributed and centralized approaches, the cell controller may filter or preprocess information that is ultimately passed back to a mainframe.

facilities are likely to combine monitoring tasks with some direct machine control. A typical use is to implement process self-tuning by automatically changing process input parameters after an alarm, perhaps eliminating the manual adjustment of a dial.

Another common role for cell controllers is as file servers. Here, the controller contains a hard disk that holds programs for numerous CNC machines or PLCs. On command, the computer sends a new program out to a given manufacturing machine. The command can come from a machine operator or might be sent down remotely from a central supervisory computer.

Cell controllers usually employ a passive backplane into which cards containing a processor and peripherals are inserted. These machines are adapted to industrial environments through use of cooling fans, NEMA cabinets, and heat sinking. Such machines can operate in ambient temperatures as high as 60°C. Some are specially designed to work without a cooling fan.

Most cell controller vendors provide software that allows the controller to communicate with widely used PLCs over networks. This software generally handles the communication protocols for local-area networks (LANs) from large PLC vendors. Such software also allows the controller to communicate over the LAN with any device that sends ASCII characters.

When cell controllers must talk to less widely used brands of PLCs, however, some custom programming may be needed.

Programmable controllers

A programmable logic controller, or PLC, is a software-based equivalent of a relay panel. A PLC is a general-purpose device. One model can be programmed to control a variety of machines, and programs can be changed easily for new jobs or changes in production routines.

PLCs were once primitive devices capable of providing only minimal feedback about machine operation and status. The situation has changed drastically, however, with the advent of more powerful computer chips and new standards that give a controller access to information throughout a manufacturing plant. Whereas the first controllers generally provided only limited information about the status of relay contacts, new monitoring capabilities let the user know exactly what is happening on the floor.

Computers have expanded PLC power through greater speed and programming flexibility. Today's PLCs almost always have a port that permits a user to tie into a computer. Three developments have helped bring about this integration of PLCs and computers: "smart" PLCs with their own microprocessors and memory, multitasking software, and local-area networks (LANs).

SCAN TIME

Scan time is an important characteristic of programmable controllers, but various models have different scan times because scan time depends on CPU design and on memory size and type. Scan times run from less than 1 to 200 ms although most PLCs have scan times of 20 to 50 ms. Fortunately, establishing a required scan time is analytically straightforward.

A programmable controller operates by examining a logic program step by step, solving the logic as it goes, and repeating that process as long as the controller operates. A programmable controller checks the status of all inputs once every scan and, after performing the necessary logic operations, resets all outputs at the end of the following scan. Thus, when the status of any output is set, it is the result of input status at the start of the previous scan.

Scan time, then, is the time required to complete one operating cycle, during which all logic is solved, all miscellaneous tasks are completed, and the outputs are reset. A PC with a 200-ms scan time completes that process 5 times a second; with a 20-ms scan time, 50 times a second.

Since every input and output is serviced once every scan, the maximum delay in actuation of an output is simply the scan time, which is fixed for any controller. The computation of required reaction time is, therefore, a straightforward evaluation of mechanical movements possible within this delay. There is no need for an evaluation of accumulated delays.

New software has enhanced the capability of computers, particularly personal computers to operate with PLCs. Until recently, small computers were limited to performing one task at a time. If a computer was being used to check the status of a controller, it could not perform data analysis or generate a report at the same time. However, with the development of concurrent DOS (disk operating system), the simultaneous juggling of two different tasks can be done.

More powerful microprocessors have resulted in controllers able to perform multiaxis control and able to link with sophisticated vision systems. One reason new PLCs are taking on such a wide range of duties is that they can be installed in modules, thus simplifying any needed customization and future expansion. Because each PLC contains its own internal communication highways or buses, additional memory or processing capability can be added by snapping in additional modules.

Various modules add RS-232 communication ports, multiaxis control and fault annunciation.

Software can be developed either on or off line; data-management and analysis programs are available. Many of the devices can be programmed from an IBM PC or compatible machine, and special industrially hardened programmers are also available when extreme temperature, dust, and vibration could be problems. I/O stations can be located up to 2,000 ft from the CPU.

A controller is no more powerful than the software available for it. Two relatively recent developments, menu-driven software and concurrent operating systems, have simplified programming and made it more useful. Programs using menus allow an operator with only minimal training to monitor, analyze, and manage processes. Concurrent operating systems switch back and forth between two different programs so fast that both appear to be running at the same time.

Some PLCs are equipped to solve problems involving mathematical functions such as sine, cosine, tangent, xy, $y\sqrt{x}$, e^x natural logarithms, and common logarithms. Such calculations are often required for energy management, process control, process modeling, real-time error correction, and many other applications.

And while ladder logic is still the standard industry programming language, most manufacturers offer versions that are programmable in Basic, C, or other high-level languages.

The ability to handle analog signals along with arithmetic and other complex calculations has made PLCs suitable for the control of processes as well as for the control of machines. Typical applications are mineral and chemical processing, water and waste treatment, and petroleum collection and distribution. In many of these applications a PLC can complement conventional

Your Industry

Berg Manufactured

Products for Quality & Service

Slides

Ball, Crossed Roller and Rack Driven:

• Straight Line Accuracy .0002 in./ in. of Travel • Positional Repeatability .0001 in. • Travel From 0.5 in. to 24 in.• Load Ratings From 4 lbs. to 180 lbs • Higher Load Ratings With Crossed Roller • Load Ratings fro 14 kg. to 58 kg. • Anodized Aluminum Bodies With Hardened Stainless Steel Rolling Members • Availabl With Aligned Precision Gear Racks • Life Expectancy as Great as 100 x 10^6 Inches of Travel • Special Configuration for Travel, Load, Length or Mounting Are Readily Available

Circle 657

Multi Beam Flexible Coupling

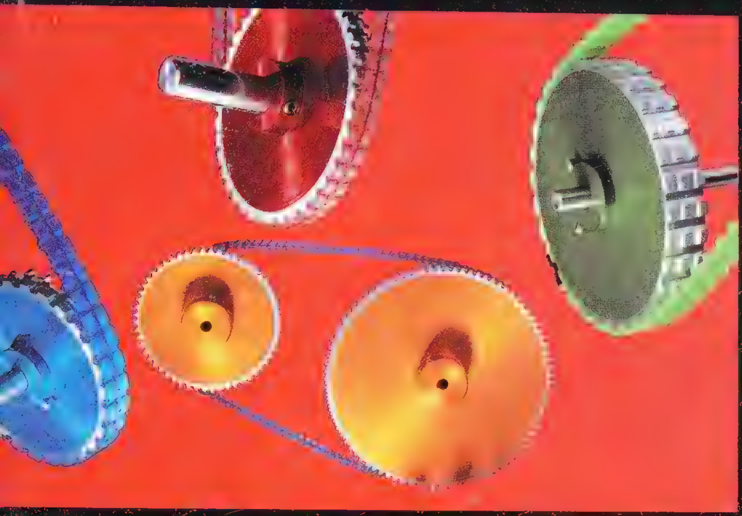
• One Piece Construction Eliminates Mechanical Joints and Possible Failure Points
• No Backlash • Constant Velocity • Torsionally Rigid
• High Flexibility •Small and Lightweight
• Speeds up to 65,000 RPM • Not Temperature Sensitive
• No Lubrication Required
• Unaffected by Climatic Conditions • Reversible
• Max. Rated Torque Up to140 N. M . (1240 lb. in.) in Stainless Steel • Angular Misalignment Up to 10 ° Bore Size 1mm-40mm (.040 in.-1.575 in.)
• Delrin and Aluminum also Available
• Attachment by Set Screw, Clamp or Keyway
• Custom Design Specials Available

Circle 656

BERG

Manufacturer of Precision Mechanical Components

Demands the Best



Belts and Pulleys

- ***Precision Instrumentation Drive Belts***
- *Ladder, Bandolier and Crossed Bandolier Configuration*
- *Up to 7° Pulley Misalignment*
- *Pitches from .1 in. to .5 in. (4mm) in Any Required Length*
- *Tensile Strength Up to 300 lbs. (670 N)*
- *Polyurethane with Steel or Aramid Spine*
- *Available in Conductive Polyether Amide for ESD Controlled Environments*
- *Quiet Running with No Lubrication Requirements*
- ***Standard Low HP, O-Ring Drive Belts***
- *Circular , Elastomeric Material*
- *3/64 in. to 1/4 in.(1mm to 6.4mm) Cross Sectional Diameter*
- *Available in 70 or 90 Durometer*
- *From .03 in. to 14 in. (.8mm to 355mm) Inside Diameter*
- *Up to15% Stretch Capability*

- ***Berg, Inc. Maintains a Full Line of Matching Sprockets and Pulleys in All Belt Families***

Circle 659

Linear Products

Gear Racks

Quality 10 (DIN 7), 16 to 64 D.P. (0.25 to 1.5 Mod) Stainless or Aluminum; Round and Rectangular Cross Sections

Adjustable Linear Bearings

Shaft Diameters .250 in. to 2.000 in. (6.25mm to 51.00mm) with Load Capabilities from 22 lbs. to 3000 lbs. (400 N to 3340 N)

Linear Bearings

Stainless, Chrome Steel or Plastic; Loads Up to 1080 lbs. (2800 N); Ball Bearing or Dry-Lube Bushing; Shaft Sizes 1/8 in. to 2 in. (6mm to 30mm)

Shafts

Soft or Hardened Stainless Steel and Hardened Alloy Steel; Diameters from 1/8 in. to 2 in. (6mm to 50mm); Lengths to 11 ft. (900mm); Shaft Hangers and Wipers are Available for All Shaft Sizes; Special end Shaft Machining Available

Anti-Backlash Nut & Screw

Zero Backlash; Delrin Nuts With Aluminum or Stainless Steel Screws; Spring Force 5 lbs. (20 N); Leads from 3/8 in. to 2-1/2 in. (10mm to 60mm); Special Nut and Screw Lengths Machined to Specification

Circle 658

BERG

Berg Inc., 499 Ocean Ave, East Rockaway, NY 11518 / General Telephone (516) 596-1700
Sales & Cust. Service (516) 599-5010 / Telex 9103506176 / Fax (516) 599-3274 or (516) 599-3277

analog control systems by handling sequence problems as well as a portion of the analog calculation and control. In support of those functions, some PLCs now have the ability to store recipes for batch processing, reducing the need for manual inputs.

In further support of their process-control capabilities, some PLCs can be equipped to solve complex equations such as proportional-integral-derivative equations required for the control of many processes. A sophisticated PLC is capable of performing these calculations on many different portions of a process simultaneously.

PLCs are also capable of producing analog outputs and of providing position control functions. PLCs can even provide control functions normally performed by numerical controls.

A modern PLC can also pass information back to the operator. It can print out its own ladder diagram for record, review, or change, or it can provide status or progress reports in English on a CRT or printer routinely or on request. A PLC can also display messages in English to summarize data or guide the operator.

Data-analysis programs are becoming increasingly common. A spreadsheet format is often used. Usually each PLC is assigned a tag or number. Parameters such as data type, coil, input, and addresses are tracked. The PLC initiates changes to data within the computer database, which initiate other control tasks. For example, if the PLC closes a valve, a software routine can be started that measures resulting flow through the valve and sounds an alarm if the flow is not within desired limits.

The programmable controller also can track down faults external to itself. This capability is useful because the machine itself and externally mounted control elements such as limit switches, solenoids, sensors, transducers, remote pushbuttons and selector switches are usually much less reliable, and more often a cause of machine downtime, than the PLC.

Other maintenance aids are available to help solve malfunctions. One feature intensifies on a CRT that portion of a circuit that is carrying current. Another feature allows an operator to command specific inputs or outputs to be unconditionally turned on or off, thus helping a technician to determine whether a problem is being caused by an internal or external failure.

PLC robot control: Programmable controllers are often equipped with special firmware (software programmed by PLC manufacturers) through which the controllers can perform many complex procedures according to simple instructions in user programs. Sequencer firmware makes possible the programming, storing, and accessing of data required for simulating the performance of electronic, or electromechanical sequencers and programmers. Sequencer data are stored in a data-table section of PLC memory, a section separate from that available for user programs. PLCs containing sequencer firmware are especially useful for control of robots where the final position of each movement is determined by limit switches or other on-off, position-feedback devices.

Robot movements can be altered by using different masks for different robot tasks. One method of loading or programming sequencers is by means of a "teach" mode. This is a technique for loading or setting up the on-off contacts in a sequencer to correspond with the on-off status of I/O points. For this method, a robot is jogged into a desired position. Pressing a "teach" pushbutton energizes a sequencer load instruction that causes the on-off status of all pertinent inputs to be copied into a sequencer step. By jogging the robot through steps sequentially, in each case pressing the "teach" pushbutton, a PLC is "taught" a sequence of movements.

Robots having closed-loop systems are controlled by PLCs through digital-to-analog (d/a) I/O modules. These modules convert digital PC signals to analog outputs having a −10 to 10-V range. The outputs serve as speed references for the hydraulic or electrical servosystems that typically power each axis. Each axis is mechanically coupled to a potentiometer or encoder that feeds position and velocity data back to a PLC, closing a feedback control loop. Digital commands from a PLC to a converter initiates motion, sets acceleration rates, determines speeds, and initiates deceleration. Motion is halted when the feedback indicates the robot has reached the proper position.

Suitably equipped programmable controllers can generally control point-to-point or vectored motion. Point-to-point movement along each axis is initiated and halted independently of other axes. This type of motion is easily programmed, requires little memory, and is suitable for many robot applications.

Vectored motion, however, requires that the movements along two or more axes be interdependent. The PLC adjusts acceleration rates and speed for each axis so that all movement terminates simultaneously. By this means a robot arm moves from point to point along the shortest path. Vectored motion control usually reduces the time required for each move. To perform vectored control, PLCs must be equipped with arithmetic firmware that calculates speeds required for each axis. Although standardized algorithms are use for these calculations, vectored motion programs are somewhat more complex and require more memory than those for point-to-point motion.

Pneumatic controls

Simple control tasks can be candidates for pneumatic, electropneumatic, and hybrid pneumatic controls. Purely pneumatic controls must be used in certain cases, as in the explosive environment found in paint-spraying operations or chemical plants. When safety is not the prime concern, a pneumatic circuit is generally more economical than electronic control when handling up to about 50 I/Os, or 12 to 20 sequencing steps. This assumes that pneumatic power components, such as cylinders or rotary actuators, are being controlled. If electrical power components, such as dc motors, are used, electronic control is probably better, even in simple applications.

In cases where either pneumatic or electronic control can be used, tradeoffs between solenoids and air-piloted valves may become important. Solenoid valves are more expensive than similarly sized air-piloted valves in many cases.

Also, air-piloted valves may respond more quickly than solenoids. A common misconception is that because an electrical signal travels faster than a pneumatic one, overall response is quicker. Actually, response depends on the element being driven. In high-speed applications, air-piloted valves are often a better choice.

Hybrid controls take advantage of both electronic and pneumatic controls. An electric-to-pneumatic interface circuit allows PLCs to control air-operated components. This enables pneumatic power components to take advantage of PLC capabilities such as reprogramming. Hybrid control of hydraulic cylinders is possible through use of air-piloted hydraulic power valves.

Timers and counters

Self-contained machines such as fryers for fast-food restaurants, cook-and-hold ovens, and bakery equipment usually employ some sort of simple au-

ORMEC
Servo Motion Control Update

Generation III Model 20 and 40 controllers offer effective solutions for multi-axis, servo motion control.

ORMEC, a leading supplier of servo motion control systems, is pleased to announce significant additions and enhancements to our successful Generation III family of servo motion control products. Here are the highlights of this major product release. More information on these products is available in this section.

Model 20 Motion Controller: This newest member of ORMEC's Generation III family is value-engineered for 1 1/2 to 4-axis applications. It includes two slots for DSP Axis Modules and/or communication adapters. The built-in RS-422 interface is plug-compatible with either our new compact industrial terminal or a numeric keypad.

A variety of product options—memory disk and MotionCARD™ slots, keyboard connector, co-processor and Extended I/O board —allow you to select the features that your application requires.

Enhanced Model 40 Motion Controller: The original member of the Generation III family, targeted for 2 1/2 to 8-axis applications, has also been upgraded. PCMCIA-standard Memory Disk and MotionCARD™ slots are included in the Model 40. A math co-processor and Extended I/O Board with Pamux support are optional.

MotionBASIC® Version 2.1: The latest version of ORMEC's industry-standard BASIC for servo motion control is included with both the Model 20 & 40 motion controllers.

This release of MotionBASIC® features advanced electronic gearing and registration features, adjustable S-curve motion profiles, software floating point, program protection, multi-revolution, absolute encoder support and many other software enhancements.

More Information

For an ORMEC Generation III *Product Guide*, applications assistance or other information:

- Call: (716) 385-3520
- FAX: (716) 385-5999
- ORMEC, 19 Linden Park,
  Rochester, NY 14625

Memory Disks: New, PCMCIA-standard Memory Disks provide up to 4 megabytes of user program and memory storage. Memory disks simplify installation and maintenance of motion programs, machine set-up and configuration files. And for manufacturers who support automation at multiple sites worldwide, the simplicity and ruggedness of this approach provides an elegant method to update software.

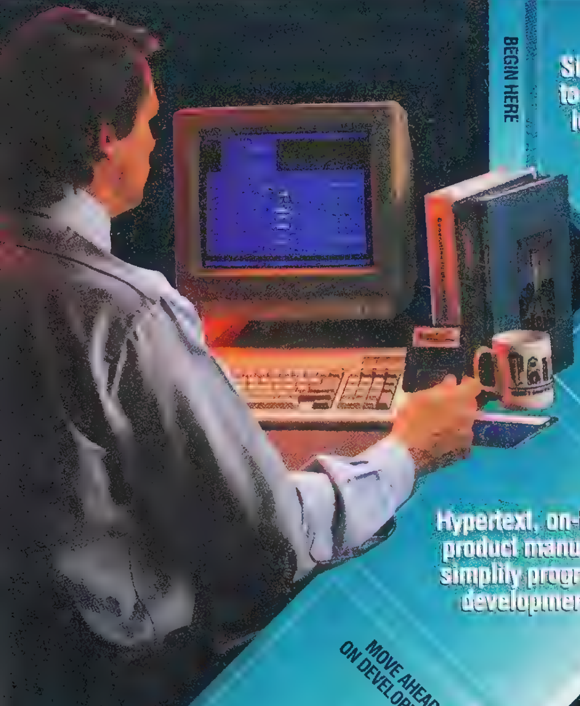
MotionCARDs™: PLC communications MotionCARDs™ provide easy to use communications with popular PLC networks—Data Highway/Plus™, Modbus™ and S908/Modbus™

By providing an easy way to set-up automatic background communications with PLC networks, they provide ability to communicate any Generation III data (e.g. torque, speed, position & diagnostic information) with PLCs and/or Man-Machine-Interfaces. Plus, the motion control system can send or receive "product recipes" in the form of MotionBASIC® variables. With S908/Modbus™, you can attach Generation III directly to the PLC remote I/O network.

Compact Industrial Terminal: ORMEC's new 8-line by 40-character industrial terminal is fully integrated with MotionBASIC® to provide a cost-effective, robust operator interface. The terminal is compact (8.5" x 8.5" x 2.5") and features a water tight NEMA 4 front panel with large, rubberized keys

Circle 135

Servo motion control that improves your performance



BEGIN HERE

Since you know how to program in BASIC, learning ORMEC's MotionBASIC® saves you time & energy.

MOVE AHEAD

Hypertext, on-line product manuals simplify program development

MOVE AHEAD ON DEVELOPMENT

Programming tools make writing software for Man-Machine Interfaces a snap.

MOVE AHEAD WITH CONFIGURABILITY

ORMEC's Model 20 & Model 40 controllers provide cost-effective solutions for applications 1½ axis and up.

PC/AT style backplanes in both controllers provides easy access to standard network, video & serial cards.

MOVE AHEAD WITH TECHNOLOGY

Generation III's multi-processor architecture always provides 5 MIPs of processing power per axis plus floating point math.

40 MHz digital signal processors provide power to perform accurate, reliable 90° indexes in as little as 10 milliseconds

Direct DSP-to-DSP communications every position loop update provides ultra-precise electronic gearing

DSPs can independently "repeat" complex gear or motion sequences to maximize performance & simplify programming.

MOVE AHEAD

APPLICATION SUCCESSES	
Reciprocating flying cutoffs	○
Form-fill-seal machines	○
Pin insertion machines	○
Trending registration systems	○
High speed point-to-point positioning	○
Composite winding machines	○
Motor armature winding machines	○
Paper, foil wind/unwind systems	○
Bag making machines	○
Labeling machines	○
Printing machines	○
Flying shear controls	○
Press feed controls	○
Packaging machines	○
Cut-to-length controls	○
Textile machines	○
Conveyor synchronization systems	○
Tension controls	○
Large factory networked systems	○

Seeing is believing! Call us today at (716) 385-3520 to set-up a demo and see how elegantly we can solve these application problems or to discuss your specific project.

KEEP MOVING AHEAD

Select from Modbus™, S908/Modbus™ & Data Highway Plus™

You can easily manipulate I/O and send or receive data on popular PLC networks.

Up to 528 analog & digital I/O plus programmable limit switches are fully integrated

Adjustable S-curve motion profiles provide smooth accelerations

MOVE AHEAD WITH FLEXIBILITY

MotionCARD™ Memory Disks provide up to 4 megabytes of program & data storage

...and simplify field installation & maintenance of machine set-up, motion programs & "product recipes"

Absolute encoders with 100,000 revolution range guarantee your system will always know its position.

ORMEC's torque mode servos eliminate tedious manual system set-up.

Our goal is to form a partnership with each customer that guarantees mutual success.

Through applications support, training and service, we'll keep you moving ahead every step of the way!

NEW Generation IV Product Guide

ORMEC Videos, "Motion Control Solutions" and "Generation III" available on request

FREE MotionBASIC™ Hypertext Demo Disks

ORMEC

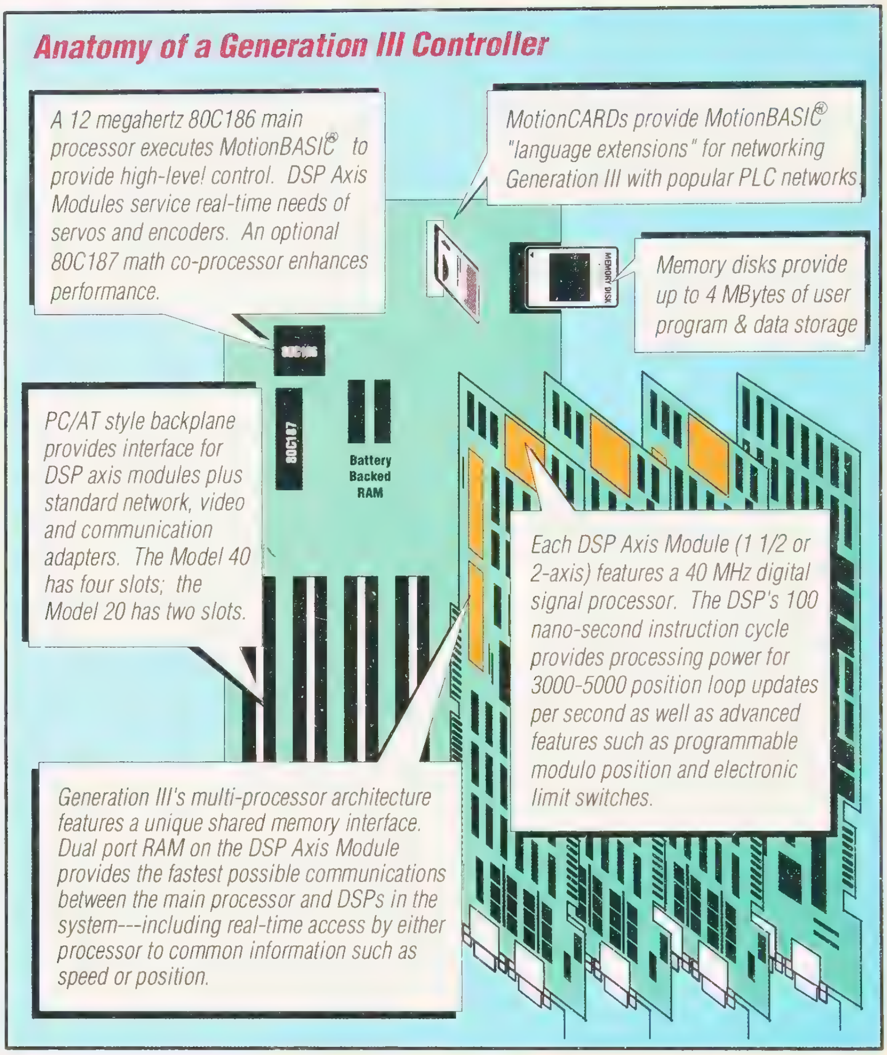
19 Linden Park, Rochester, NY 14625
(716) 385-3520 FAX: (716) 385-5999

[illegible]

Circle 135

A Family of Motion Controllers

ORMEC sells motion controllers, but thats not what you're really after. What you want are the things a motion controller can do for you—provide high-performance, controlled motion that is powerful, easy to use and exceptionally reliable. Our goal with Generation III is to supply our customers reliable hardware that provides a fully-integrated, plug-compatible solution.



Anatomy of a Generation III Controller

A 12 megahertz 80C186 main processor executes MotionBASIC® to provide high-level control. DSP Axis Modules service real-time needs of servos and encoders. An optional 80C187 math co-processor enhances performance.

MotionCARDs provide MotionBASIC® "language extensions" for networking Generation III with popular PLC networks.

Memory disks provide up to 4 MBytes of user program & data storage

PC/AT style backplane provides interface for DSP axis modules plus standard network, video and communication adapters. The Model 40 has four slots; the Model 20 has two slots.

Each DSP Axis Module (1 1/2 or 2-axis) features a 40 MHz digital signal processor. The DSP's 100 nano-second instruction cycle provides processing power for 3000-5000 position loop updates per second as well as advanced features such as programmable modulo position and electronic limit switches.

Generation III's multi-processor architecture features a unique shared memory interface. Dual port RAM on the DSP Axis Module provides the fastest possible communications between the main processor and DSPs in the system---including real-time access by either processor to common information such as speed or position.

Fully integrated for your needs

Generation III is a family of integrated, multi-axis motion controllers that provides solutions for a wide variety of application needs. Here's an overview of the new Generation III Model 20 and upgraded Model 40 controllers:

Multi-Processor Architecture: By tightly interfacing the controller's main processor with high-speed digital signal processor(s) on the DSP Axis Modules, Generation III offers unsurpassed motion performance. A shared memory interface, utilizing dual port RAM, guarantees fastest possible inter-processor communications.

DSP Performance: In addition to the DSP's ability to insure superlative closed loop operation, Generation III includes MotionDATA™—a direct DSP-to-DSP link for electronic gearing applications.

PC-AT Style Backplane: Generation III's open architecture allows you to plug-in DSP Axis Modules (1 1/2 or 2-axis versions)—plus standard network, video and serial cards. Optional adapters are fully integrated into the MotionBASIC® software environment.

User program storage: 60 Kbytes of lithium battery backed CMOS static RAM (plus 20K for program comments) is adequate for most applications.

Memory Disks: But if your application requires additional memory, PCMCIA-standard memory disk (Flash PROM or Static RAM) technology can provide up to 4 Mbytes of additional memory. Memory disks are also ideal for simplifying field installation and maintenance of motion programs and product recipes.

MotionCARDs™: These EPROM memory cards can be plugged into the controller to provide MotionBASIC® language extensions for specialized application needs such as PLC network communications.

Machine I/O: Generation III features 16 discrete I/O points compatible with Opto-22 style modules. They are accessed at pluggable terminal blocks & are individually software-configurable as inputs or outputs. Inputs can be configured as latched—allowing them to capture high speed sensor signals—and may also be used to interrupt program operation. MotionBASIC® accesses all I/O as pre-defined arrayed variables.

Extended Machine I/O: Generation III's optional Extended I/O Interface includes 24 TTL-level I/O points at a 50-pin Opto-22 compatible connector. These I/O points are configurable as inputs or outputs, or this connector can access 512 analog or digital I/O points using Opto-22's Pamux standard.

DSP Axis Modules: Each DSP Axis Module interfaces two servos, or a pacer encoder and a servo, and provides full fault diagnostics including open wire detection, servo alarms & alarm codes, and watchdog timer interlocks.

DSP Axis Module I/O: Each DSP Axis Module also provides two high-speed sensor inputs, four 12-bit analog inputs and six programmable limit switch outputs---as well as hardware overtravel limits.

Motor/Drive Interface: The servomotor/drive interface has been carefully designed—with a thorough consideration of cabling, shielding and voltage tolerances.

Communication Ports: An RS-232 serial port is provided for program development using an IBM-PC or compatible running our MotionPRO™ software. The built-in RS-422 serial port is fully supported in software to provide an elegant interface with operator keypads, compact terminals or Modbus™ for factory communications.

System Diagnostics: Sixteen digital I/O LEDs and 22 diagnostic LEDs make it simple to diagnose many problems immediately without test equipment.

Model 20 Motion Controller

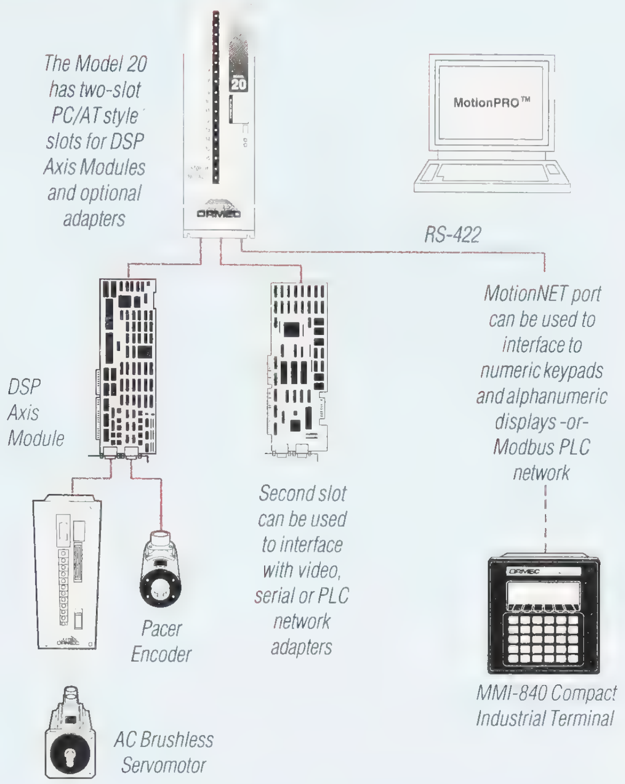
ORMEC's new Model 20 Motion Controller (list price: $2795) is targeted for 1 1/2 to 4-axis applications and is effective in two basic configurations—based on the application's use of the controller's two PC/AT style slots:

1 1/2 & 2-axis configurations: In these applications, the Generation III Model 20 uses either an ORMEC 1 1/2 or 2-axis DSP module to control two AC servomotors or one servomotor and a remote encoder interface. The other slot provides easy access to video, serial or network adapters. Plus the RS-422 MotionNET™ port can be used to interface Generation III with Modbus™, our compact industrial terminal or other serial devices.

2 1/2 to 4-axis configurations: In these applications, DSP Axis Modules occupy both slots in the controller's backplane. The RS-422 MotionNET™ port can be used for Modbus™ communications or to interface Generation III with a keypad, a compact industrial terminal or other serial devices.

While the Model 20 is designed to share the same fundamental technology and many features with the Model 40 controller, the product options outlined in the chart below show how the Model 20 allows you to select among specific features your application may require.

1 1/2 Axis Model 20 System Example


The Model 20 has two-slot PC/AT style slots for DSP Axis Modules and optional adapters
20
ORMEC
MotionPRO™
RS-422
DSP Axis Module
MotionNET port can be used to interface to numeric keypads and alphanumeric displays -or- Modbus PLC network
Second slot can be used to interface with video, serial or PLC network adapters
Pacer Encoder
ORMEC
MMI-840 Compact Industrial Terminal
AC Brushless Servomotor

Model 40 Motion Controller

ORMEC's upgraded Model 40 Motion Controller (list price: $3795) is targeted for 2 1/2 to 8-axis applications. The Model 40 features four PC/AT slots for DSP Axis Modules and optional communication adapters.

In addition, with the release of MotionBASIC® Version 2.1, the Model 40 features a new motherboard which offers PCMCIA-standard memory card slots for both a memory disk and a MotionCARD™---plus a lithium battery holder for absolute encoder support.

Both the math co-processor and Extended I/O Board, previously standard on the Model 40, are now optional.

Memory Disks

A key new introduction—standard with the Model 40 and optional for the Model 20—provides support for PCMCIA-standard memory disks for user program and data storage. A user can conveniently plug-in up to four megabtyes of program and data storage using either Flash PROM or SRAM technology.

Memory Disks

Memory Disks provide easy installation and maintenance of motion programs, machine set-up files and "product recipes". Simply plug-in a rugged, "credit card sized" module to load information into the motion controller. This is especially important in remote plant locations—since it eliminates the need for a computer and skilled technician to perform on-site updates.

Memory Disks are available in two types: Flash PROM and SRAM.

Flash PROM Memory Disks, (512K to 4M bytes) have "write speeds" similar to a disk drive and provide "memory speed" access to disk data. And a key advantage is that Flash PROM is *inherently non-volatile.*

SRAM Memory Disks (512K to 2 M bytes) are battery-backed and feature "read" and "write" speeds similar to random access memory (RAM). Battery life is four years, not counting the time the card is plugged into Generation III—and memory will even survive a few days with the battery removed from the card. SRAM is ideal for dynamically changing information and is required for writing random access files.

Generation III Model 20 & 40 Standards/Options

Features	**Model 20**	**Model 40**
PC/AT-style slots	2	4
Targeted Applications: Number of Axes	1 1/2 - 4	2 1/2 - 8
16 Discrete I/O: individually selectable as inputs or outputs	Standard	Standard
Dual-slot memory card controller	Optional	Standard
Keyboard connector/controller	Optional	Standard
Math co-processor	Optional	Optional
Extended I/O Board *(16 Digital I/O, Direct access to 24 slot I/O rack or Pamux Extended I/O support)*	Optional	Optional

Circle 135

How MotionBASIC coordinates with Generation III's multi-processor architecture

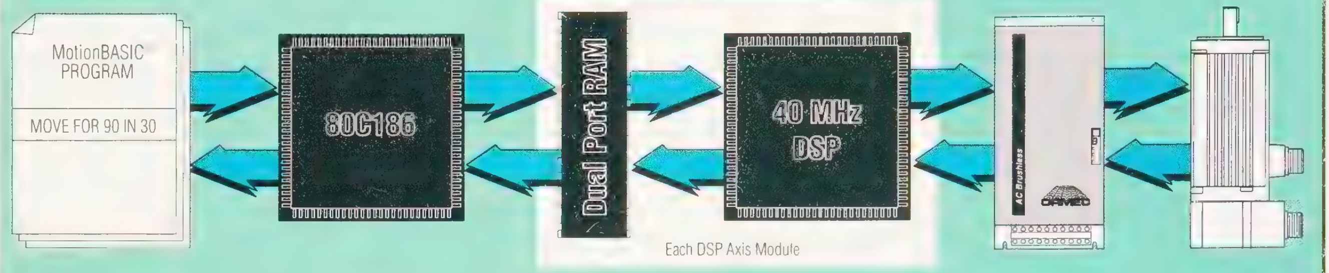
The combination of a distributed architecture & interpretive MotionBASIC® provides high performance software which combines speed with ease of use

Main processor interprets MotionBASIC® MOVE and GEAR statements and writes data packet(s) in dual-port RAM memory

Data packets concisely define distances, speeds and accelerations for the DSP Axis Module(s) from MotionBASIC® parameters

The processing power and numerical precision of the DSP makes it ideal for high performance real-time loop control ... freeing the main processor for other tasks

Each DSP updates position and velocity up to 5,000 times per second and handles all the real-time servicing of the servo system



Servodrive fault diagnostics and system error reporting are fully integrated with MotionBASIC®

MotionBASIC® access to real-time information is simplified by pre-defined parameters for each axis or group of axes and includes automatic user unit conversion

Key motion parameters such as speed, torque and position maintained in dual-port RAM by the DSP can be accessed directly by the main processor

Each DSP Axis Module also has analog inputs, high speed sensor inputs and programmable limit switch outputs which can be coordinated with motion

DOS-Like File System

A "DOS-like" file system supported by ORMEC's MotionBASIC® programming language and MotionPRO™ development software, is both powerful and easy to learn. Standard BASIC file management commands simplify interaction with Memory Disks and allow the user to format the disk, display files, make/change/delete directories and rename or kill disk files.

Accessing Data Files

MotionBASIC® also includes statements that provide access to sequential and random-access data files on the memory disk. Plus memory disks provide essentially unlimited memory for large application programs.

A sequential data file, for example, could be used to save "on disk" mathematical array values that define complex wind segments for traverse winding "recipes".

Or a random-access data file can be used to define "pin patterns" and "locations" for machines that insert pins into electrical connectors.

ORMEC has extensive applications experience in both traverse winding and pin insertion machines—and could easily demonstrate this capability at your facility. If interested, call our Applications Engineering group at (716) 385-3520 to set-up a demonstration.

For a free MotionBASIC® Hypertext disk, call ORMEC at (716) 385-3520

MotionBASIC® Version 2.1

On the software side, Generation III provides the worlds most widely used programming language---BASIC---now enhanced with features for high performance motion control.

Motion + BASIC = MotionBASIC®

ORMEC's MotionBASIC® is a superset of Microsoft BASIC, which adds motion control and industrial I/O using English-like motion statements and pre-defined variables. MotionBASIC® incorporates BASICs strengths---the simplicity of an interpreter, the richness of the language, plus English-like keywords and syntax---into a complete solution for industrial motion control.

BASICs of MotionBASIC®

- ► Full-featured programming with English-like keywords and syntax
- ► Variable types include floating point, double precision floating point, integer, long integer, string and set.
- ► Symbolic program labels eliminate program references to line numbers and speed program execution
- ► Block programming structures such as WHILE ... WEND and multi-line IF THEN ELSEIF ELSE ENDIF
- ► Powerful screen input with INPUT @ USING statement
- ► Hardware interrupt processing using the ON EVENT GOSUB statement
- ► Math functions including sine, cosine, tangent
- ► Built-in editor integrated with multi-level syntax checking
- ► Powerful debug features include TRACE, TRACE VAL & BREAK

User Units

All MotionBASIC® parameters are expressed in the units of your choice... degrees, inches, millimeters, RPM, msec, etc., making your BASIC program easy to understand. For example: MOVE FOR 90 (degrees) IN 30 (msec)

User units are exact because they are converted to the units of the individual position transducers using rational numbers.

MOVE statement

The MOVE statement provides a powerful way to command motion for one or more servomotors. It can be used to "MOVE AT" a specified speed, "MOVE FOR" a desired distance or "MOVE TO" an absolute position. Acceleration and deceleration can be specified independently as a function of time or distance, or as rates.

A single MOVE statement can even be used to simultaneously move multiple axes AT independent speeds, FOR independent distances or TO independent positions.

GEAR statement

The GEAR statement brings similar elegance to electronic gearing applications where motion must be tightly synchronized with a pacer encoder or master axis.

User unit conversion factors allow the statement GEAR AT 1 TO 1 to perfectly maintain synchronization of the output shafts of servo-driven gearboxes even though the servos have different position transducer resolutions and different gearbox ratios.

The GEAR statement also allows the follower servo to "cam-in" an intermittent motion to the pacer encoder as a function of travel of the pacer encoder or the follower axis. If user-units are in degrees, the statement GEAR FOR 360 IN 360,90,180 will cause the follower servo to rotate for 360°, accelerating during the first 90° of rotation, running at top speed for the next 90° and decelerating during the next 180° of rotation of the pacer servo.

Superimposed motion

The GEAR FOR and MOVE FOR statements can also be used to superimpose motion on top of a constant ratio "GEAR AT" motion, meeting the needs of a wide range of sophisticated electronic gearing applications. For example, this capability provides a simple means of making phase adjustments between electronically geared servos either ratiometrically or as a function of time.

Repetitive motion

MotionBASIC® allows you to queue repetitive motion sequences for local execution by individual DSP Axis Modules. Repetitive motion sequences operate totally independent of the main processor, freeing it for other tasks & can be synchronously replaced as needed. If required, these motions can include time delays or be synchronized with sensors within one position loop update.

S-Curve Acceleration Profiles

MotionBASIC® supports S-curve velocity profiles for MOVE statements. Shape of the S-curve can be adjusted by specifying the percentage of the acceleration & deceleration zones which should have an S-curve. S-curve is functionally derived & updated at each position loop update (3,000 to 4,000 times per second). It automatically maintains the S-curve shape for motions which might have vastly different distances, speeds & accelerations.

Absolute Encoder Support

MotionBASIC® also provides support for multi-revolution, absolute encoders. These cost-effective encoders measure and maintain absolute position for up to ±49,999 revolutions of motor movement, even with power off.

Generation III AC Brushless Servomotors & Drives

Generation III is fully compatible with a wide range of AC brushless servomotors and drives---and offers guaranteed servo performance

- speeds to 4,500 RPM
- torques, conservatively rated from 1.2 to 560 lb-in stall
- rated power from fractional to 8.2 HP
- standard encoder resolutions to 24,000 counts per revolution

All of ORMEC's servomotor/drives operate as torque mode servos for maximum performance. Systems using torque mode drives eliminate manual servodrive set-up and allow the user to specify velocity loop parameters as numerical data in a motion control program. Direct software control over commanded torque & torque limits is also useful in many applications.

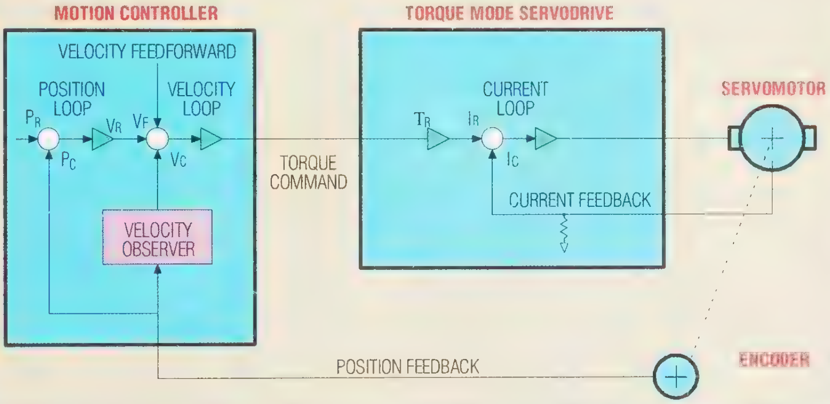
Here are just a few additional advantages of torque mode systems:

Maintainability: Replacement drives require no adjustment at all, since velocity loop parameters and torque limits are set in software.

Performance: Uniform performance is obtained because loop parameters are stored in the motion controller, and are not dependent on manual adjustments.

Velocity Loop Adjustability: The power of DSPs for processing applications such as velocity loop algorithms allow these controls to handle large load to motor inertia mismatches. Load to motor inertia ratios of 15:1 are common.

Torque Limiting & Monitoring: Easy access to parameters such as peak torque provides design flexibility. Monitoring torque data can provide valuable information about the machine or process under control.



MMI-840 Compact Industrial Terminal

Our new NEMA 4 rated, industrial terminal (list price: $1245) is a compact, cost-effective operator interface.

The MMI-840 industrial terminal provides an eight-line by 40-characters backlit LCD display ideal for motion control applications. The unit is compact (8.5"w x 8.5"h x 2.5"d) and has a water tight NEMA 4 front panel.

It runs on 24 VDC power supplied by the Generation III controller--and is easily interfaced via the built-in RS-422 MotionNET™ port.

Fully Integrated with MotionBASIC®

MotionBASIC® provides an elegant software interface to the MMI-840 that is accessed by simply opening the terminal as the console device. Once this is done, all console program I/O is automatically directed to the MMI-840.

This includes:

- full-screen addressing
- *clear screen* and *clear to end of line*
- our powerful screen-oriented INPUT@ statement
- full use of the eight function keys including interrupts using BASIC's standard KEY, KEY(n) and ON KEY GOSUB capabilities.

The fact that MotionBASIC® has the unique capability to separate program I/O from program development communication simplifies development of applications using the MMI-840.

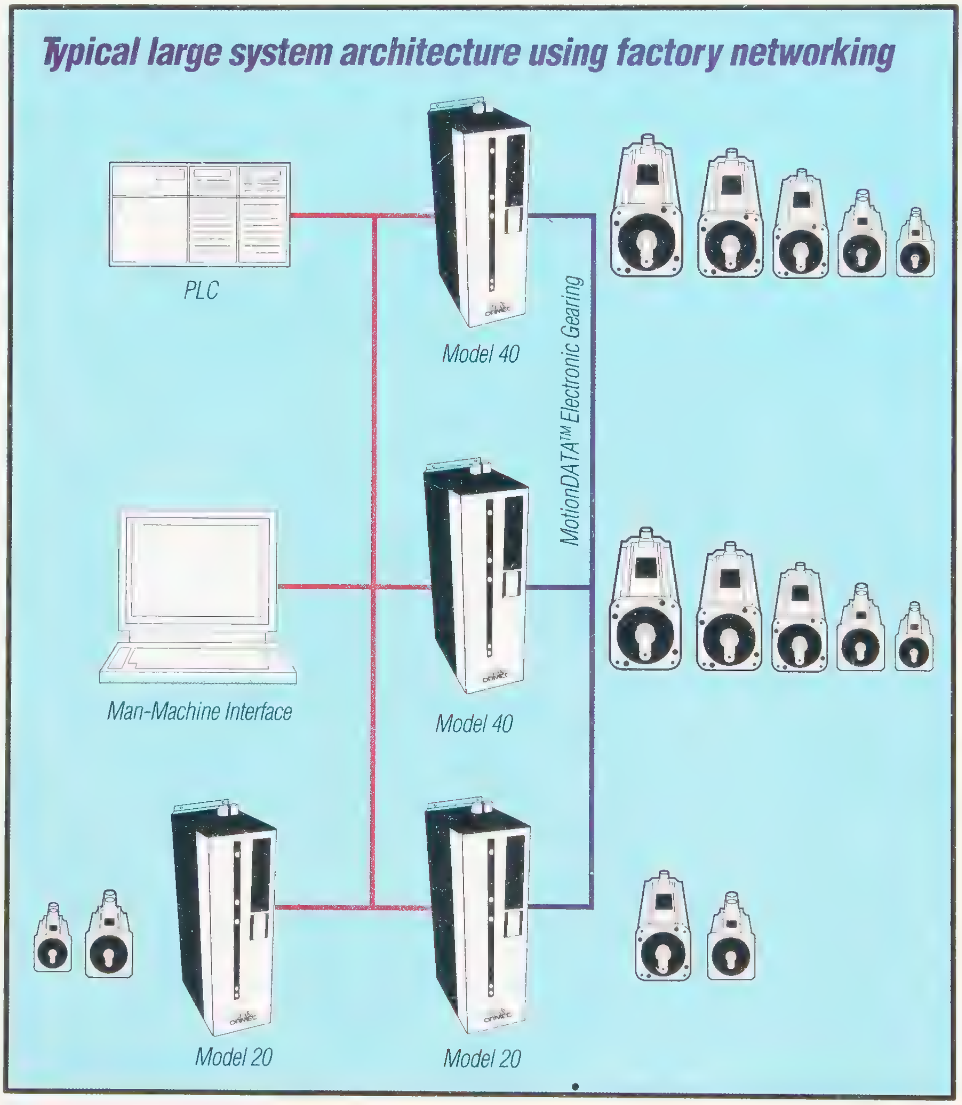
PLC Communication MotionCARDs™

PLC Communication MotionCARDs™ provide access to popular PLC factory networks. They are supplied on a plug-in MotionCARD™---and include a menu-driven SETUP program and a hypertext on-line manual. They provide automatic background communication with the following PLC networks:

- Allen-Bradley's Data Highway/Plus™
- Modicon's Modbus™
- Modicon's S908/Modbus™

The use of a factory network allows a motion control system to share information with PLCs and/or supervisory computers, including the ability to:

- Communicate any Generation III data (e.g. torque, speed, position and diagnostic information) with PLCs and Man-Machine Interfaces
- Send or receive customer product recipes in the form of MotionBASIC® variables.
- Attach Generation III directly to PLC remote I/O using Modicon's S908 remote I/O.


Typical large system architecture using factory networking

Generation III & PLC Networks

Installation, set-up & testing of factory communications is simplified by menu-driven, set-up programs

Once initial installation is completed, the user executes a MAP statement *only once* to map each selected MotionBASIC® variable to a PLC register. Data transfer betwee the PLC and motion controller, from that point on, happens automatically and is transparent to program operation.

PLCs can also initiate MotionBASIC® subroutines by changing specific register values designated by ON REGISTER GOSUB statements

Modbus™ Communications

Modicon's Modbus™ represents the least expensive PLC network communication alternative.

This approach uses standard serial communications hardware and can conveniently interface to either the Model 20 or 40 using a Communications Adapter or the MotionNET™ port.

Modbus™ is a master/slave network which has a ***single master*** device. The master originates all communications and can be a computer, Man-Machine Interface or Generation III motion controller. Modbus™ supports up to 247 slave devices which can provide or receive information on the network, but cannot initiate communications.

Generation III can be either network master or slave, but not both. Modicon PLCs must always be slaves

Data Highway/Plus™ Communications

Allen-Bradley's Data Highway/Plus™ is a powerful, peer-to-peer network communications product.

Using Data Highway/Plus™ requires installation of a high speed network adapter in the Generation III backplane. Its communications co-processor coordinates with Generation III to maintain MotionBASIC® performance (generally 90% or more) even with heavy network traffic.

Data Highway/Plus™ utilizes a token-passing scheme that rotates mastership among any station on the network---and operates at 57.6 Kbaud over twinax cable. While Data Highway™ allows up to 256 stations, Data Highway Plus™ provides faster communications in most motion control applications which have 20 stations or less.

S908/ Modbus™ Communications

The S908/ Modbus™ alternative provides both high-speed, remote I/O *and* Modbus™ communications on a single, high-speed coax cable.

Again, a high-speed network adapter (with a co-processor) is installed in the Generation III controller's backplane to enhance performance. This allows communications to occur at PLC scan rates (typically 4-40 msec). The network operates at 1.5 MHz on coaxial cable.

Generation III operates as a remote I/O drop with up to 200 I/O points (160 remote and 40 local). During one PLC scan, 160 remote I/O points and 16 integer variables can be transferred, Alternatively, you can transfer up to 24 integer variables and 64 I/O points.

Circle 135

tomatic controller. A typical controller includes one or more timer functions and, occasionally, a counter to turn the process on and off at programmed intervals as in response to some external event.

Timers and counter controls can be either electromechanical or solid state. They control a set of relay contacts on the basis of settings dialed or keyed into their front-panel controls.

In general, single-function electromechanical devices are used when the cost factor is more important than high accuracy. One reason is that these devices are less accurate than a solid-state unit. Their setting resolution is limited by the analog setting mechanism they use.

As a general guideline, electromechanical devices are adequate when the timing accuracy can vary by ±1% of full scale. Digital solid-state timers are preferred when better accuracy is needed. The setting resolution of a digital device is, in fact, the time value of the least-significant digit. If the timing range of the device is 0.01 to 99.99 s, settings can be increased or decreased in increments of 0.01 s.

Another important factor is repeatability or the degree to which the timer can repeat the same time setting. Solid-state timer accuracy has improved immensely from the early days of resistor/capacitor networks. One reliable technology uses the ac line frequency as a timing base. Repeat accuracy with this technology is constant to the line frequency. Another technology uses an internal quartz oscillator as its timing base.

A typical repeat accuracy for a solid-state device is on the order of 0.003% or 35 ms, whichever is larger. Typical setting accuracies are usually ±0.1% of the setting or 50 ms, whichever is larger.

Industrial counters are mechanical, electromechanical, or electronic instruments that totalize a series of events and actuate contacts at predetermined counts. Most counter inputs accept either voltage pulses or simple switch closures. Some counters also have a control input used to start (enable) or reset the counter either to a present number or to zero.

If the counter can add and subtract events from a total, it may also have an up/down input that controls the direction of the counts received. Some models also provide separate inputs for up-count events and down-count events.

Counter output can be a simple numerical display (count totalizer), a switching action (predetermining counter), a coded electrical signal, or a printout. Most counters have a dial, thumbwheels, or keyboard for entering the count number. Once the counter reaches the predetermined count, the output switch contacts transfer. Some counter accept no further counts at this point until reset through the reset/enable control input.

Electronic counters use all solid-state components and digital counting elements, hence they can accept high-speed inputs to provide counting rates faster than mechanical and electromechanical counters. These devices generally use logic-level, electrical pulse, or switch-contact inputs to provide counting speeds on the order of 10 kHz. Many include LED or neon-lamp displays that indicate the predetermined count as well as the totalized count. Most have CMOS logic circuitry and include a stand-by battery.

Computerized counters generally contain single-chip microcomputers that provide predetermining and totalizing counter functions for several simultaneous operations. Most devices include solid-state memory to retain

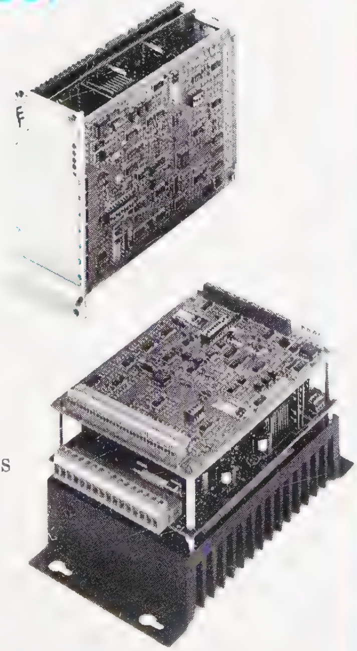
Elmo.
The Proven Experts
In Powerful Servos

NOW - DISTRIBUTION & SERVICE CENTER IN THE U.S.A.

Our new center in Greenville, South Carolina was opened this year. In this center we stock hundreds of amplifiers, enabling a faster delivery time for most of our products.

The World's Smallest
3KW Brushless
Amplifier.

One of our stock items is the world's smallest 3KW Brushless Amplifier: The EBA - 10/330 is a 10A, 330V servo amplifier for brushless motors. It is based on MOSFET technology and SMT components. The result is a Eurocard size with king size performance and quality. The flexible design enables use of all common feedback sensors, such as a Brushless Tacho, Tachsyn and Resolver. The EBA amplifiers match all DC brushless motors in the market - and have the best record of proven performance.



Elmo Motion Control Inc.

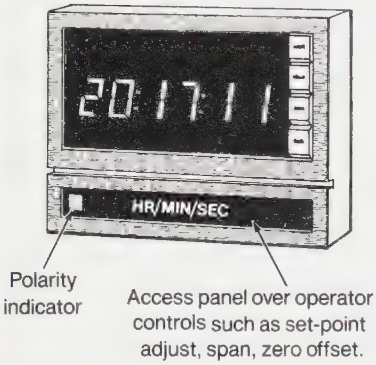
1200 Woodruff Road, Suite C-22, Greenville, SC 29607, USA, Tel: (803) 288-9316, Fax: (803) 288-9318

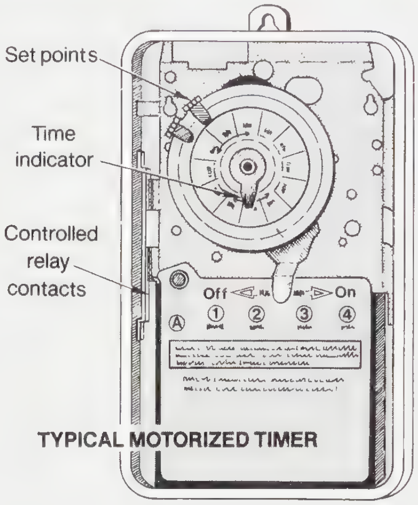
Circle 136

data in the event of power failure and accept unidirectional and bidirectional signals for up/down counting.

Most computerized counters have many of the same characteristics as electronic timers, including high-speed counting, remote or automatic reset, and pushbutton (or keyboard) reset. Additional capabilities include prescaling (multiplying input signals by a constant factor to match flow metering, machine drive ratios, and so forth) and prewarning, where a secondary control input is switched to provide a warning signal that the predetermined count will soon occur. ■

TYPICAL PANEL-METER TIMER/COUNTER


20:17:11
HR/MIN/SEC
Polarity indicator
Access panel over operator controls such as set-point adjust, span, zero offset.



The major components of a typical motorized reset timer include a synchronous timing motor and clutch coil. Application of power energizes the clutch coil, which closes contacts to energize the motor and start the timing period. At time out, other contacts deenergize the clutch coil, and the motor stops. Contacts can be opened or closed in different sequences, which are made by the orientation and location of trip bar lugs. Typical standard features include cycle progress pointers and pilot lights indicating when the timer motor is energized.

Typical timing and time range specs

	Maximum range	Minimum setting	Dial divisions	Repeat accuracy	Reset time	Power-on response
High-quality motorized timer	5s	⅙s	0.05s	±0.05s	0.5s at max. setting	28 ms ave. pull in, 17 ms ave. drop out
	10s	⅓s	⅙s	±0.05s		
	15s	½s	¼	±0.08s		
	30s	1s	½s	±0.15s		
	60s	2s	1s	±0.3s		
	150s	4.5s	2s	±0.75s		
	5min	9s	3s	±1.5s		
	10min	20s	10s	±3s		
	15min	30s	15s	±4.5s		
	30min	1min	½min	±9s		
	60min	2min	1min	±18s		
	150min	4.5min	2min	±45s		
	5h	9min	3min	±1.5min		
	10h	20min	10min	±3min		
	30h	1h	½h	±9min		
	60h	2h	1h	±18min		
Solid-state timer	99.99s	0.01 s	Setting accuracy ±0.05% of setting or 50 ms, whichever is larger	±0.001% of setting or 35 ms whichever is larger	15 ms max.	200ms
	999.9s	0.1 s				
	9999 min	1 min				
	999.9 min	0.1 min				
	99.99 h	0.01 h				
	999.9 h	0.1 h				
	99 min:59s	1 s				
	99 h:59min	1 min				

SEQUENCERS

Production machines normally operate in sequential cycles, where one operation follows after the previous one has been completed. The pneumatic sequencer acts as a central "switchboard" to route control commands to the actuators and monitor the progress of the machine cycle. The use of pneumatic sequencers can lower costs by eliminating the need for I/O cards, independent power supplies, and protective equipment.

Pneumatic sequencers consist of a series of identical modules (called step, stage, or event modules) mounted on a common track. Each module controls one step in the machine cycle, sending a pneumatic signal that triggers movements in each step and receiving a pneumatic feedback signal that indicates completion of the movements.

The sequencer has two common channels. One supplies pressure to each step-module memory element; the other provides a general reset signal for resetting the entire sequencer.

Step modules are integrated circuits consisting of three basic logic elements: memory, AND, and OR. Also included are output and feedback connections, and a position indicator. Manual overrides can be included as well.

In operation, the memory element of the first step module is set (turned on) by a pressure signal from the machine control unit. Output from the memory element performs three actions:

1. Provides a working output signal for that step in the operation.
2. Pressurizes one input of its own AND element.
3. Resets (turns off) the preceding step module (if there is one) through the OR element.

The second input to the AND element is pressurized by the feedback signal, which indicates that the movements prescribed for that step have been completed. This signal activates the AND element and turns on the memory element for the following step module. This sequence continues until the end of the machine cycle.

MECHANICAL SYSTEMS

Advertisers

A&A Manufacturing Co., Inc. 215
AVM, Incorporated, An Arvin Co. 163
American Precision Industries, Inc., Deltran Division 131
American Variseal, A Division of W.S. Shamban & Co. 221
Apple Rubber Products, Inc. 209-212
Bal Seal Engineering Company, Incorporated 215
Barden Corporation, The 285
Bayside Controls, Inc. 172-173
Bearings Incorporated 257-264
Berg, Winfred M., Inc. 4-5,76-77,268-269
Browning Mfg.-Emerson Power Transmission Corp. 197-200
Carlyle Johnson Machine Co., The 165
Cunningham Industries, Inc. 207
Dodge/Reliance Electric 19-21,94-95,112-114,126-127,176-183,248-253
Dover Instrument Corporation 123
Duff-Norton 131
Dynaroll Corporation 307
Eaton Corporation Airflex Division 151-154
Efson, Inc. 131
FAG Bearings Corporation 290
Force Control Industries, Inc. 149
Furon, Mechanical Seal Division 207
GAM Enterprises Inc. 170
Garlock Bearings Incorporated 239-242
Graphite Metallizing Corporation 280
Gray & Prior 165
Habasit Belting, Inc. 103-106
Harmonic Drive Technologies 186-189
Hi-Lo Manufacturing Company 147
IKO International, Inc. 299
INA Bearing Company, Inc. 267
ITW Spiroid 195
Inertia Dynamics/Reliance Electric 166
Intech 215
Interroll 289

A
Axial face seals 223
B
Babbitts 246
Ball bearings 278
Ball screws 156
Bearing materials 246,288
Bearing mounts 243
Bearings 238
Bearings, angular-contact 281
Bearings, nonmetallic 256
Bearings, plain 238
Bearings, rolling-element 278
Belt material 107
Belts 96
Belts, metal 118
Brakes 147
Bronze & copper alloys 254
Bushings, keyless 101
C
Cable carriers 161
Cams 166
Chains 118
Chains, plastic 120
Circumferential seals 225
Clutches 132
Compression packing 230
Compression seals 208
Couplings 92
Cycloidal drives 184
D
Diaphragms 234
Dry-film lubricants 303
Dynamic seals 216
E
Electromechanical actuators 155
Engines, IC 168
F
Face seals 214
Felt seals 221
Filament-wound bearings 270
Flat-way bearings 295
Flexible couplings 92
Flexible shafts 164
G
Gaskets 208
Gear boxes 171
Gear drives, intersecting-shaft 186
Gear teeth 124
Gearing tolerances 128
Gears 124
Gears, plastic 125
Gear terminology 124
Grease 301
H
Hydrodynamic bearings 275
Hydrostatic bearings 276

Components for drivelines

Fixed and variable-speed drives

Gaskets, seals, and packings

Lubricants and bearings

Joyce/Dayton Corporation 166
Kanematsu USA, Inc. 131,167
Linear Industries,
  LinTech Division 123
Machine Components Corporation 165,205
Matrix Engineering Limited 167
Mayr Corporation 129
McGill Mfg.-Emerson
  Power Transmission Corp. 200
Morse Industrial-Emerson
  Power Transmission Corp. 198
New Hampshire Ball Bearings, Inc. 245
Niagara Gear 205
Nook 157-160
Ogura Clutch 131,167
Ohio Gear, A Division of
  Regal-Beloit Corporation 194
Oil-Rite Corporation 307
PIC Design 122
Parker Seal 226-229
Pow-R-Jac, Division of
  Limitorque Corporation 148
Presray Corporation 222
Robertshaw,
  Tennessee Division 232-233,304-305
SEW Eurodrive, Inc. 193
Seal Master Corporation 217-220
Sepac, Inc. 169
Star Linear 271-274
Stock Drive Products/Sterling
  Instrument, Div. of DSG 121
Sumitomo Machinery Corporation
  of America 203
THK America, Inc. 283
Tech-Assist Corporation 119
Techno, A DSG Company 117
Thomson Industries, Inc.,
  Nyliner Division 279
Thomson Saginaw Ball Screw Company 91
Torrington Company, The 287
S.S. White Industrial Products 167
T.B. Wood's Sons Company 97-100
Warner Electric/Dana Corp. 57-63,66-67,108-110,134-146

I
Indexing drives 168
Instrument bearings 294
J
Jewel bearings 266
L
Large-diameter bearings 298
Linear actuators 156
Linear bearings 293
Lip seals 223
Lubricants 292
Lubricating systems 306
M
Metal belts 118
Multispeed drives 192
N
Needle bearings 286
Noncircular gears 124
O
Oils 300
O-rings 208
P
PV Factors 255
Packings 230
Plain-bearing design 238
Plain-bearing materials 246
Planetary gearing 194
Plastic chain 120
Plastic gears 125
Porous-metal bearings 255
Pressure-energized seals 213
R
Radial ball bearings 278
S
Seal life 223
Seal materials 236
Seal selection 224
Sealants 234
Shaft mounts 101
Sheaves and pulleys 111
Silent chain 122
Solid lubricants 302
Spherical bearings 284
Split-ring seals 225
Springs 162
Synthetic lubricants 302
T
Tapered bearings 284
Thin-section bearings 282
Thrust bearings 282
Traction drives 204
Transmissions 194
U
Universal joints 161
V
Variable-pitch drives 201
Variable-stroke drives 202
Vibration analysis 192

EIGHT TIMES THE LEAD ACCURACY IN HALF THE LEAD TIME

You win two ways when you design your products using Precision Plus* ground-thread ball screws from Thomson Saginaw*.

First, you get lead accuracy of .0005"/ft (or better), instead of .004"/ft common to rolled-thread assemblies. For eight times more-accurate positioning and repeatability in machine tools, pick and place materials handling systems, electronic component insertion systems, and photo enlargers, to name a few. And you get operating efficiencies above 90%.

Second, Precision Plus ball screws of this class are catalog products with standard diameters and leads. So you can have your units in hand, in half the time it takes for custom ball screws.

Because they meet world class precision standards for helical uniformity, runout and perpendicularity, you can use them anywhere with confidence. And design with eight times the lead accuracy in half the lead time.

Call or fax us today for a copy of the new Precision Plus Tech Bulletin; the name of a distributor near you; or the Thomson Saginaw Linear Actuator Technology Guide.

For Immediate Assistance
Phone: (517) 776-4123
Fax: (517) 776-3632
Or Write: Thomson Saginaw
Ball Screw Company, Inc.
628 N. Hamilton
Saginaw, MI 48602

Circle 137

THOMSON SAGINAW*
First in Linear Actuator Technology

*Trademark of Thomson Industries, Inc. THOMSON is registered in U.S. Patent and Trademark Office and other countries.

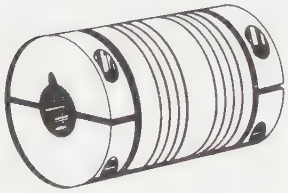
Components for drivelines

Driveline components transmit and control power and motion. As simple as this sounds, it is necessary on every machine.

The joining of two shafts is done with mechanical couplings. The coupling should be capable of transmitting the rated torque capacity of the shaft while accommodating any misalignment between the shafts.

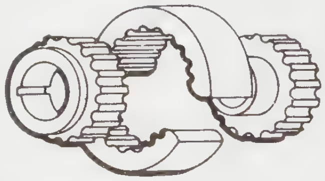
Rigid couplings are simple and low cost. But they demand almost perfect alignment of the mating shafts. And the shafts must have stable bearing supports. Misalignment, whether present initially or developed from wear, causes undue forces and accelerated wear on the shafts, the coupling, the

FLEXIBLE COUPLINGS



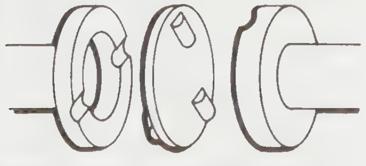
One-piece helical: Designed as a curved beam that transmits motion with no backlash and with constant velocity under misalignment. The one-piece coupling is manufactured from such metals as aluminum alloys and stainless steels. Also, the low-mass design is adaptable to high-speed applications and requires no lubrication.

Gear: The most widely used type of shaft coupling. Consists of two hubs with external teeth engaging internal teeth on a two-piece sleeve that fits over both hubs. The hubs are keyed to the shafts. In another variation, the sleeve is one piece and slips over the external-toothed hubs. Not shown in the illustration are flanged hubs that fit over the assembly and lock it together.



Curved teeth are recommended for couplings subjected to large misalignment so that individual teeth are not overloaded. Special coupling designs are available to provide overload protection, telescoping or sliding action, and the capability for carrying radial loads.

Backlash in the gear mesh allows 1° total angular misalignment for straight teeth or 3° for curved teeth on the hub and straight teeth on the sleeve. With proper gear profiles, the coupling provides constant velocity. This type of coupling transmits high torque in a small package and allows for axial shift in the shaft. But it generally needs a lubricant and good shaft alignment.

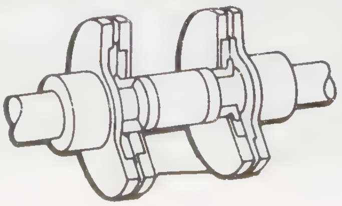


Sliding disc: Intended for low-speed, high-torque drives with minor misalignments. Two facing slotted flanges, attached to the shafts, are keyed together by a disc having projections that fit into the slots. There is enough clearance to allow sliding movement between disc and flanges.

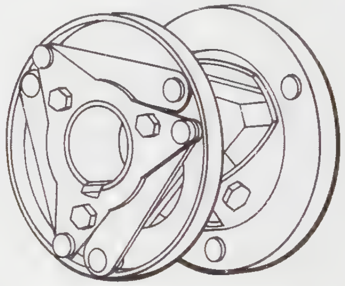
This permits a small diameter for a given torque rating. But overall length is somewhat greater than that of other types. The shaft must be moved for repair or replacement of the coupling.

Allowable misalignments are ¼° angular, 1/16 to ½ in. parallel, and end play of 3/32 to ¼ in.

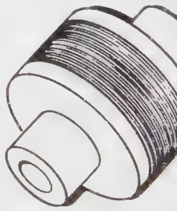
Diaphragm: Similar to the flexible-disc coupling except that torque is transmitted through contoured, metallic diaphragms. Elastic deflection of the diaphragms accommodates angular misalignments to ¼° and parallel misalignments to 0.058 in./in. of spacer length. Highly competitive in the power range above 400 hp and the speed range from 15,000 to 30,000 rpm.



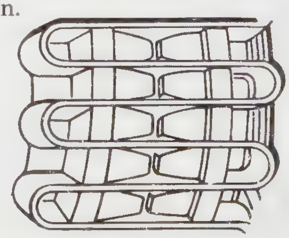
Flexible link: Three cantilever beams or links, arranged in a triangle, attach to hubs and torque sleeves so each link can flex in a given path without interfering with adjacent links. Takes angular, parallel, and axial misalignment.



Metal bellows: For light-duty applications up to 2 hp. Flexing is provided by bellows action. Allowable misalignments are 9° angular, ⅛ to ½ in. parallel. Runs at speeds in excess of 10,000 rpm. Used primarily in instrument sizes.



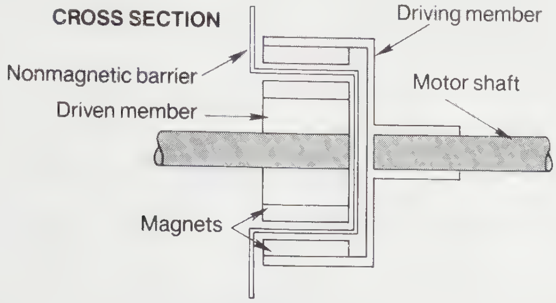
Steel grid: Operates at speeds to 6,000 rpm. Consists of two facing slotted flanges joined by a flexible steel band laced through the slots. Lubrication is required. Allowable misalignment is 1° angular, ¼° of shaft diameter parallel, and ⅛ to ½-in. end play. Has capability for torsional flexibility and shock absorption.



Magnetic coupling: Contains three primary elements - a driving and a driven member, both containing permanent magnets, and a nonmagnetic barrier. The coupling develops torque through interaction of the two sets of magnets. Torque ratings run from a few oz-in. to over 500 lb-ft.

In fluid-handling pump applications, the nonmagnetic barrier can be part of the pump housing, eliminating the leaky seals where an ordinary drive shaft penetrates the housing. Since there is no physical contact between driven and driving elements, heat and vibration transfer are minimized.

A major limitation of these couplings is the temperature dependence of the magnetic properties, but different magnet types have a range of properties.



Thermal properties of commercially available magnets

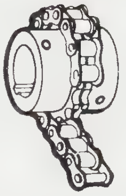
Magnet material	Temperature coefficient %/°C B_r	$(BH)_m$	H_c	Limiting temperature °C
Ferrites	−0.2	−0.19	−0.35	85
SmCo5	−0.045	−0.1	−0.06	150
Sm2Co17	−0.03	−0.07	−0.035	200
Neodymium	−0.15	−0.25	−0.4	100
Alnico	−0.025	−0.01		500

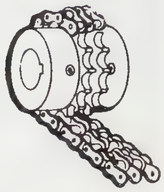
Roller chain: Low-cost, high-torque coupling tolerant of small misalignment. Consists of two sprockets, each attached to a different shaft, wrapped in the same roller chain. The sprockets are keyed or splined to the shafts.

Clearance between chain and sprockets allows angular misalignment in the range of ¼ to 1¼°, parallel misalignment of about 0.010 in., and end float in the range of 0.020 to 0.070 in.

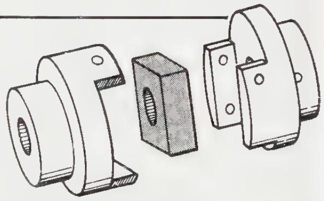
The chain is installed or replaced easily without disturbing either shaft, and the coupling is torsionally rigid. Operation is often noisy and lubrication is required. At high speeds a cover is needed to retain lubricant.

The double-roller version allows a more compact installation (because it has an additional line of tensile plates), but the single-roller type provides slightly more end-float tolerance.

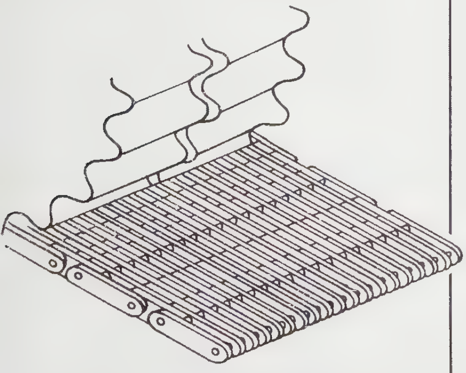

SINGLE ROLLER


DOUBLE ROLLER

Sliding block: Similar in principle to the sliding-disc type, but capable of withstanding greater angular misalignment (up to 3°). Flanges with C-shaped jaws are connected to the shafts and engage a common square block that rides between them. The block is normally made from a self-lubricating metal or plastic. The coupling accepts parallel misalignment up to 10% of shaft diameter and takes end float of 1/32 to ½ in.



Silent chain: Intended for heavy-duty drives, with ratings up to 3,000 hp at 1,800 rpm. The coupling is similar in operation to the roller-chain coupling, but uses silent chain wrapped around two wide sprockets.



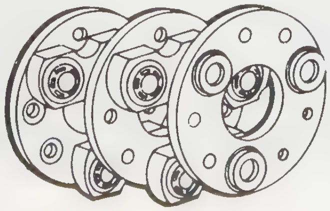
These couplings can take 1 to 2° of parallel misalignment on 2% chain pitch. End play is ⅛ to 1 in.

Bore sizes range from ⅜ to 8 in. with torque rated according to the shaft that fits the maximum bore of the hub. Operating speeds go as high as 5,000 rpm.

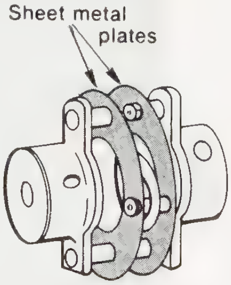
Plastic chain: Identical to roller chain in principle, but with chain links and pins made of nylon or acetal instead of steel. Requires no oil or grease and, thus, can be used in food-processing and textile machinery. Can also be used in corrosive environments.

This type is the quietest of all chain couplings, but can carry only light loads and is not tolerant of shock. Angular misalignments of ¼° per sprocket engagement are allowed, as is 0.005-in. parallel misalignment and 3/32-in. end float.

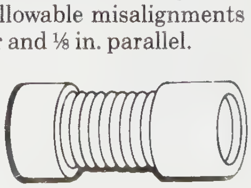
Schmidt: Torsional forces are transferred through a series of plates by mechanical linkages while allowing great translation of the rotating axis of each plate. Input and output axis can be displaced one plate diameter or more.



Flexible disc: Has no rubbing or friction surfaces that require lubrication. Torque is carried through sheet-metal plates mounted to shafts and intermediate plates by two-point supports. Flexing in the sheet metal accommodates angular misalignments of 1°, parallel misalignment of 1/64 to 5/64 in., and end play of 1/32 to 7/32 in.



Spring: Available in capacities ranging from instrument sizes to couplings capable of transmitting 240 hp. Needs no lubrication. Runs at speeds of 6,000 rpm. Allowable misalignments are 4° angular and ⅛ in. parallel.

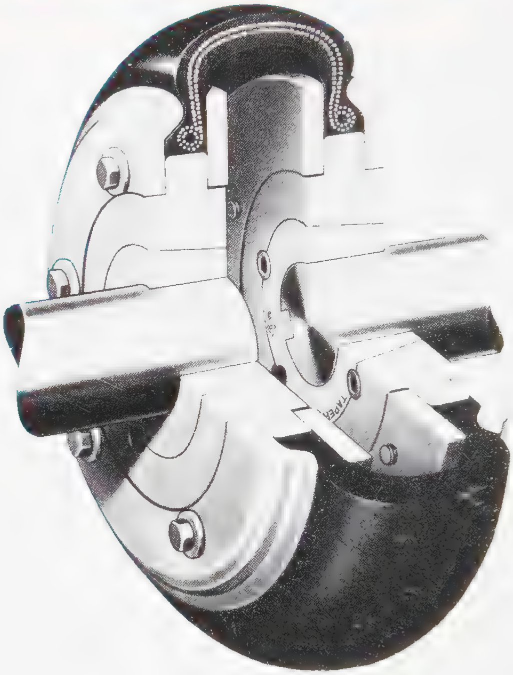


DODGE

DODGE® PARA-FLEX® FLEXIBLE CUSHION COUPLINGS

COUPLING DATA SHEET

The Original Problem Solver Elastomeric Coupling



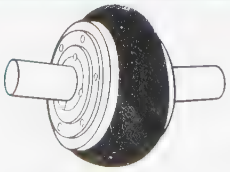
The best answer for misalignment, end float and shock loads

PARA-FLEX couplings are unique. They accommodate angular misalignment, parallel misalignment and end float—singly or in any combination—and cushion shock loads to lengthen machine life. Result: 4-way savings in less downtime and maintenance.

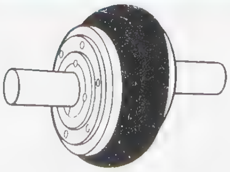
Industry's Leading Elastomer Coupling—

The PARA-FLEX coupling has been proven by over 30 years of successful applications in the steel, cement, rubber, paper, lumber and other heavy industries. It's the number one choice where rugged dependability is important.

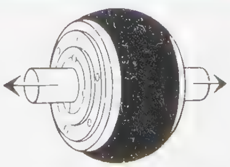
Features	Benefits
Flexible Non-Metal Element	Elastomeric element with synthetic tension members bonded together in natural rubber with additional reinforcement at the split ends in the elements. Results in amazingly long life. Handles angular misalignment to 4°, parallel misalignment to 1/8″ and end float to 5/16″. Cushions shock loads and dampens torsional vibration.
No Lubrication	No lubrication is necessary which makes PARA-FLEX ideal for applications where cleanliness is essential such as the food, textile and chemical industries
Temperature Range	The standard element is compounded natural rubber and has an operating temperature range from −45°F to +180°F. The optional neoprene element has an operating range from −40°F to +210°F.
TAPER-LOCK® Flanges	TAPER-LOCK simplifies mounting with no reboring or machining necessary.



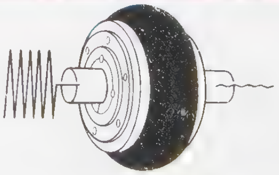
- TAKES ANGULAR MISALIGNMENT



- TAKES PARALLEL MISALIGNMENT



- TAKES END FLOAT



- DAMPENS VIBRATION

DODGE

PX50 thru PX120 PARA-FLEX Couplings Using TAPER-LOCK Bushings

Cplg. Size	Bore Range of Bush		Max. RPM	Wt. (Cplg. w/o Bush.)	A	B	E	M ■	N	Y Dia B.C.	Z		AB
	Min.	Max.									No. of Screws per Flange	Screw Size	
PB40	1/2	1 1/8	5730	1.6	4	2 1/2	§	3/4	7/8	—	—	—	—
PX50	1/2	1 1/8	4500	4.3	5 1/4	2 5/16	7/8	17/32	7/32	2 3/8	5	1/4-20x1 1/8	31/32
PX60	1/2	1 3/8	4000	8.0	6 1/2	2 51/64	1	23/32	9/32	3 5/16	5	5/16-18x1 1/4	1 9/32
PX70	1/2	1 5/8	3600	11.6	7 3/8	3 1/64	1	61/64	9/32	3 7/8	5	5/16-18x1 1/2	1 1/2
PX80	1/2	2	3100	16.8	8 3/8	3 3/16	1 1/4	49/64	9/32	4 5/8	6	5/16-18x1 1/2	1 1/2
PX90	1/2	2 1/2	2800	23.2	9 1/4	3 13/32	1 3/4	21/64	5/16	5 1/4	6	3/8-16x1 3/4	1 17/32
PX100	1/2	2 1/2	2600	32.4	10	3 37/64	1 3/4	33/64	5/16	6	6	3/8-16x1 3/4	1 23/32
PX110	1/2	2 1/2	2300	46.5	11	3 29/32	1 3/4	15/32	5/16	6 1/2	6	3/8-16x2	1 9/16
PX120	7/8	3	2100	64.0	12 3/8	4 5/32	2	7/16	7/16	7 1/4	6	1/2-13x2	1 3/4

PX140 thru PX320 PARA-FLEX Couplings Using TAPER-LOCK Bushings

Cplg. Size	Bore Range of Bush		Max. RPM	Wt. (HF (Cplg. w/o Bush.)	A	B			D	E	M ■	Y Dia B.C.	Z		AB
	Min.	Max.				Type HF	Type HH	Type FF					No. of Screws per Flange	Screw Size	
PX140	1 3/16	3 15/16	1840	133.2	14 1/8	7 13/16	7 13/16	7 13/16	7 1/2	3 1/2	13/16	9 3/16	8	1/2-13x2 1/2	2 1/16
PX160	1 7/16	4 1/2	1560	208.8	16 5/8	9 3/16	9 3/16	9 3/16	8 5/8	4	1 3/16	10 7/8	8	5/8-11x3	2 11/16
PX200	1 15/16	4 15/16	1300	372.5	20	10 5/16	10 5/16	10 5/16	10 1/4	4 1/2	1 5/16	12 7/8	12	5/8-11x3 1/2	3 5/16
PX240	2 7/16	5 5/16	1080	626.7	24 1/8	11 29/32	11 29/32	11 29/32	11 1/2	5	1 29/32	16 1/4	12	3/4-10x4	3 29/32
PX280	4 15/16	7	910	996.5	28 1/2	15 3/32	14 7/32	15 31/32	17	6	2 7/32	19 1/2	14	7/8-9x3 1/2	4 7/32
PX320	5 7/16	8	810	1442	32 1/2	15 11/16	15 1/16	16 5/16	17	6 1/2	2 1/16	23	16	7/8-9x3 1/2	4 1/2

PX50 thru PX90 Finished Bore PARA-FLEX Couplings

Cplg. Size	Max. RPM	Max. Bore	Size X Stk. Bore	A	B	E	H	M ■	N	Y Dia. B.C.	Z		AB
											No. of Screws per Flange	Screw Size	
PX50FB	4500	1 3/8	5/8, 7/8, 1, 1 1/8, 1 3/8	5 1/4	2 5/16	7/8	4 3/32	17/32	17/32	2 3/8	5	1/4-20x1 1/8	31/32
PX60FB	4000	1 13/16	1, 1 1/8, 1 3/8, 1 5/8	6 1/2	2 51/64	1	5	23/32	9/32	3 5/16	5	5/16-18x1 1/4	1 9/32
PX70FB	3600	2 3/16	1 5/8, 1 7/8, 2 1/8	7 3/8	3 1/64	1	5 45/64	61/64	9/32	3 7/8	5	5/16-18x1 1/2	1 1/2
PX80FB	3100	2 11/16	1 7/16, 1 7/8, 2 1/8	8 3/8	3 3/16	1 1/4	6 5/8	49/64	9/32	4 5/8	6	5/16-18x1 1/2	1 1/2
PX90FB	2800	2 7/8	1 7/16, 1 7/8, 2 1/8	9 1/4	3 13/32	1 3/4	7 33/64	21/64	5/16	5 1/4	6	3/8-16x1 3/4	1 17/32

PX60 thru PX320 Type BBS PARA-FLEX Couplings

Cplg. Size	Max. RPM	Max. Bore	A	B	D	E	M ■	N	Y Dia. B.C.	Z		AB
										No. of Screws per Flange	Screw Size	
PX60BBS	4000	1 1/2	6 1/2	4 9/32	2 3/8	1 1/2	1 9/32	9/32	3 5/16	5	5/16-18x1 1/4	1 9/32
PX70BBS	3600	2 1/8	7 3/8	5	2 15/16	1 3/4	1 1/2	9/32	3 7/8	5	5/16-18x1 1/2	1 1/2
PX80BBS	3100	2 9/16	8 3/8	5 1/2	3 11/16	2	1 1/2	9/32	4 5/8	6	5/16-18x1 1/2	1 1/2
PX90BBS	2800	2 3/4	9 1/4	6 1/32	4 1/8	2 1/4	1 17/32	5/16	5 1/4	6	3/8-16x1 3/4	1 17/32
PX100BBS	2600	3 1/4	10	6 31/32	4 15/16	2 5/8	1 23/32	5/16	6	6	3/8-16x1 3/4	1 23/32
PX110BBS	2300	3 15/16	11	7 9/16	5 7/16	3	1 9/16	5/16	6 1/2	6	3/8-16x2	1 9/16
PX120BBS	2100	4	12 3/8	8 1/4	5 13/16	3 1/4	1 3/4	7/16	7 1/4	6	1/2-13x2	1 3/4
PX140BBS	1840	4 1/2	14 1/8	9 13/16	7	3 7/8	2 7/16	7/16	9 3/16	8	1/2-13x2 1/4	2 1/16
PX160BBS	1560	6	16 5/8	12 15/16	8 1/2	5 1/8	2 7/16	7/16	10 7/8	10	1/2-13x2 1/2	2 1/16
PX200BBS	1300	6 3/4	20	15 9/16	9 3/8	6 1/8	3 3/4	1/2	12 7/8	12	5/8-11x3	3 5/16
PX240BBS	1080	7 1/2	24 1/8	14 5/32	10	5 1/8	4 11/32	19/32	16 1/4	12	3/4-10x3 1/2	3 29/32
PX280BBS	910	9	28 1/2	18 15/32	12	7 1/8	4 21/32	11/16	19 1/2	14	7/8-9x4	4 7/32
PX320BBS	810	11	32 1/2	20 3/4	14	8 1/8	4 15/16	11/16	23	16	7/8-9x4 1/2	4 1/2

PS50 thru PS200 PARA-FLEX Spacer Couplings

Cplg. Size	Wt. Cplg. w/ Bush.	Shaft Spacing		Bore Range		Max. Operating Speed of Cplg. (RPM)	A Dia.	D Dia.	E	G	K	N	Bolt Circle Dia. P	No. & Size of Screws per Flange Q	AB
		Min.	Max.	Min.	Max.										
PS50	10.7	2 7/8	4 3/8	1/2	1 1/4	4500	5 1/4	2 15/32	1	. . . .	. . . .	3/16	3 3/16	4-5/16-18x1	31/32
PS60	14.2	3	4 3/4	1/2	1 5/8	4000	6 1/2	3	1	. . . .	. . . .	11/32	3 13/16	5-5/16-18x1	1 9/32
PS70	20.2	3 1/2	7 1/2	1/2	2	3600	7 3/8	3 9/16	1 1/4	. . . .	. . . .	1/16	4 3/8	5-5/16-18x1	1 1/2
PS80	29.8	3 1/2	10	1/2	2 1/2	3100	8 3/8	4 1/4	1 3/4	. . . .	1/4	. . . .	5 1/4	6-3/8-16x1 1/4	1 1/2
PS90	33.9	3 1/2	8 1/2	1/2	2 1/2	2800	9 1/4	4 1/4	1 3/4	. . . .	1/4	. . . .	5 1/4	6-3/8-16x1 1/4	1 17/32
PS100	40	3 1/2	8 1/2	1/2	2 1/2	2600	10	4 1/4	1 3/4	. . . .	1/4	. . . .	6	6-3/8-16x1 1/4	1 23/32
PS110	51	3 1/2	9 3/16	1/2	2 1/2	2300	11	4 1/4	1 3/4	. . . .	1/4	. . . .	6	6-3/8-16x1 1/4	1 9/16
PS120	86.2	4 1/2	9 3/16	7/8	3	2100	12 3/8	5 5/8	2	. . . .	1/8	. . . .	7 1/4	6-1/2-13x1 1/2	1 3/4
PS140	198	6 7/16	13	1 3/16	3 15/16	1840	14 1/8	7 11/16	3 1/2	7/16	1 7/16	. . . .	6 11/16	5-1/2-13x4 1/2	2 1/16
PS160	317	8 1/16	11 7/16	1 7/16	4 7/16	1560	16 5/8	8 5/8	4	9/16	1 1/2	. . . .	7 1/2	6-5/8-11x5	2 11/16
PS200	462.8	9 15/16	12 7/8	1 15/16	4 15/16	1300	20	10	4 1/2	9/16	1 1/2	. . . .	8 1/2	8-5/8-11x5 1/2	3 5/16

■ Distance between flanges. Slight end float is permissible.

Specify DODGE® PARA-FLEX®
Move faster with the leader.™

DODGE/P.O. Box 499/Greenville, S.C. 29602-0499/803-297-4800/FAX: 803-281-2318

© Reliance Electric Company, 1990

Circle 138

RELIANCE ELECTRIC

shaft bearings, or the machine housing.

In most coupling applications, misalignment is the rule rather than the exception. It comes from such sources as bearing wear, structural deflection, thermal expansion, or from the settling of machine foundations. When misalignment is expected, a flexible coupling must be used.

Common selection factors include:

- Amount of torque
- Positive shaft engagement
- Misalignment tolerance
- Lubrication/maintenance
- Ease of installation/removal
- Operation under adverse conditions
- Service life
- Cost

Belts

Belts provide an efficient load transfer between shafts on a wide variety of applications. They also perform special tasks such as speed ratio variation, power transmission in more than one plane, clutching, torque limiting and shaft synchronization.

Compared to most forms of power transmission, belts often provide the best overall combination of design flexibility, low cost and maintenance, ease of drive assembly, and space savings.

Disadvantages on some applications may include the need to retension belts periodically to avoid slippage (note: overtensioning can damage bearings on pulley system); deterioration because of severe exposure to chemicals and lubricants; and the requirement that damaged belts must be replaced, rather than repaired. Although V-shaped belts are not recommended for drives with a fixed-center distance, or low-speed, high-torque applications, synchronous belts will often solve these design considerations.

Many OEM products use commercially available belts and sheaves or pulleys. This facilitates mass-produced designs, and allows OEM customers to obtain stock replacement parts easily and quickly from local distributors.

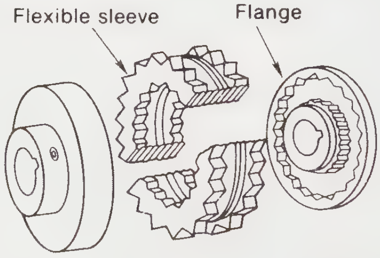
Some OEMs have belts made especially for their use. Many times the belt is actually a stock item, with a standard construction, but with a special private brand label. In other cases, a special construction belt will be developed for unique application needs such as clutching, temperature extremes, idler use, extremely high loads, or small-diameter drives.

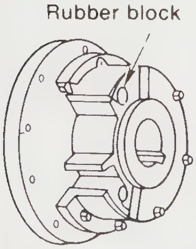
Advanced application methods and years of experience from reputable belt manufacturers generally assure good performance without extensive OEM field testing. This is especially true where operating characteristics are predictable and the load and speed range is rather small such as on electric motors in combination with fans, pumps, conveyors, and so on. However, suppliers recommend a field test to assure proper belt performance when speeds, loads, or both vary significantly, or when customer operating practices cannot be accurately predicted.

The following section describes belt types and cross sections generally available at the OEM level and in the marketplace. Most manufacturers have special belt sections or constructions which are developed for special applications, or which have higher performance characteristics. Belt manufacturers also offer special assistance to OEMs with unique applications. See

ELASTOMERIC FLEX MEMBERS

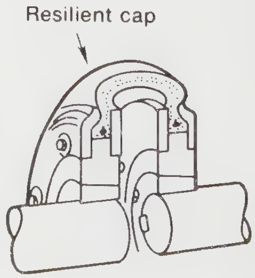
Flexible-sleeve coupling: Two flanges with internal teeth engage a flexible sleeve with external teeth. The couplings have high torsional flexibility and are tolerant of shock and vibration. Allowable shaft misalignment is 1°; allowable axial displacement is ½ in. to ⅜ in.





Rubber block: This coupling utilizes rubber in compression. The rubber blocks are installed in cavities formed by internal sleeve blades, external hub blades and two end closures. The cavities and rubber block configurations are designed to provide combinations of properties — such as high load-carrying capacity and shock absorption, or low torsional stiffness for torsional vibration attenuation, and in both cases, selective vibration-damping properties. Capacities range from 10 to over 20,000 hp per 100 rpm with misalignment capacities of 1° angular, 1/16 to ½ in. parallel offset and 1/16 to ¼ in. axial — depending upon size and operating speed.

Shear: Two facing coupler plates are capped and joined with an element shaped and constructed somewhat like an automobile tire. In a variation of this principle, resilient spacers are attached to both faces of the coupler plates. In both types, misalignment and torsional shock loads are absorbed by shear deflection in the resilient element. The shear version deflects more under load compared to the compression version, thus the shear type absorbs impact better.



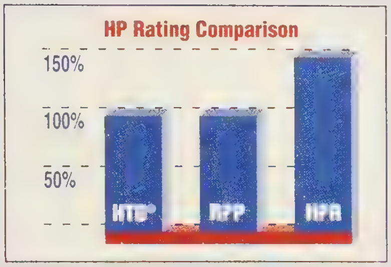
Compression: Made in a variety of designs. All basically employ resilient plates or spacers that serve as a compression cushion between metal elements connected to the shafts. The resilient member may be a disc containing holes that accept metal pegs on the facing coupler plate; or it may be a shaped spacer riding between interleaved lugs on the facing coupler plates somewhat akin to the principle of the sliding-disc coupler. The resilient member is either rubber, neoprene-impregnated fiber, or polyurethane. Capacity ratings range from 500 hp per 100 rpm, with speeds up to 6,500 rpm. General benefits of all elastomeric couplings include vibration insulation, accommodation of misalignment, and long service life without maintenance.

The Quiet Revolution.

Wood's HPR synchronous drives offer greater horsepower, lower noise.

Boost Horsepower, Not Belt Size. More compact drives are possible because a 50% increase in horsepower may be directly converted to nearly a 50% decrease in either belt width or in sprocket diameter. This reduction in size saves you money. Wood's HPR belts, which are available in 8, 14, and 20mm pitches, feature a parabolic tooth design.

Runs Quietly. The belt construction and tooth profile combined with narrower belts reduce noise significantly. A noise reduction of 10 dBa or more is possible depending upon application. So you get maximum horsepower and minimum noise.


HP Rating Comparison

Quality That Lasts. HPR belts feature a graphite self-lubricating tooth covering and internal high-tensile strength glass fiber cord. Using the HPR belt as a direct replacement for a standard-rated belt will result in increased drive capacity and a greater expected belt life. And our new, stronger HPR sprockets are designed to make a perfect match with the belts for long life without slippage or wear.

And if you don't need the horsepower boost, check out our standard RPP belts, the cost-effective alternative that still offers long life and low noise.

For more information on the drive with power to run quietly, contact your local distributor or call us.
Phone: (717) 264-7161
FAX: (717) 264-6420
In Canada:
Phone: (519) 271-5380
FAX: (519) 271-3094

Wood's The quality endures

PTDA

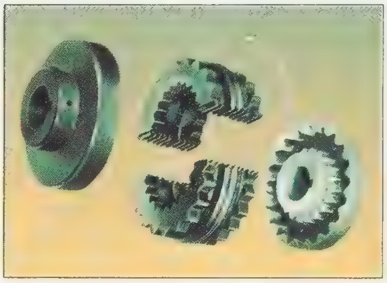
Circle 139

®HTD is a registered trademark of the Gates Rubber Co.

This coupling started a revolution that has lasted for thirty years.

Sure-Flex® means no lubrication, no maintenance and no problems.

Thirty years ago, hazards like shock, vibration and misalignment routinely caused shaft and bearing failures. Then, Wood's developed the Sure-Flex Coupling, a torsionally soft, extremely flexible coupling that absorbs all kinds of shocks and misalignment.



Even today, a Sure-Flex Coupling absorbs three to five times more shock and vibration than the leading competition. Sure-Flex Couplings are easy to install and require no lubrication and no maintenance.

For more information on durable Sure-Flex couplings, call your Woods distributor. Or, in the U.S., contact the T. B. Wood's Sons Company, Chambersburg, PA 17201 (717) 264-7161, or in Canada, the T. B. Wood's Canada Ltd., Stratford, Ontario N5A 6V6 (519-271-5380).

Wood's The quality endures.

INDUSTRIAL DISTRIBUTORS

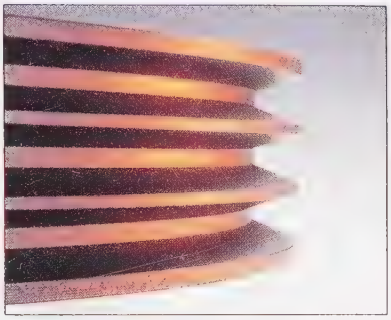
PTDA

Circle 140

Who says you can't hurry quality?

Wood's quality sheaves are in stock, in all sizes.

The Wood's V-drive sheave you need is in inventory, ready to go. But just because we deliver virtually any size sheave on a moment's notice doesn't mean we compromise quality for quick. Quite the opposite.



Wood's builds stock sheaves from 1-groove 2.20″ O.D. to 12-groove 71.0″ O.D. models under the most demanding quality standards in the industry. We make them in our own foundry from close-grained, high tensile cast iron. And finish, balance and test them in our own facilities. For easy installation or removal, our own Sure Grip® QD Bushings provide 4-way mounting flexibility and a secure clamp fit.

To get Wood's quality sheaves in a hurry, contact your distributor. Or, in the U.S., contact the T. B. Wood's Sons Company, Chambersburg, PA 17201 (717) 264-7161. In Canada, the T. B. Wood's Canada Ltd., Stratford, Ontario N5A 6V6 (519) 271-5380.

Wood's The quality endures.

PTDA

INDUSTRIAL DISTRIBUTORS

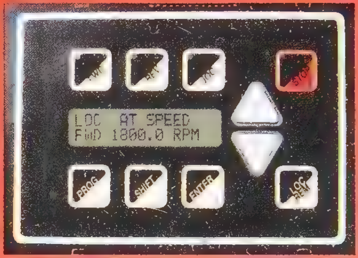
Circle 141

Big Value, Small Package.

The world's smallest NEMA 4 inverters are quality made in the U.S.A.

Wood's E-trAC WFC Series inverters have broken the NEMA 4 size and price barrier. Now you can fit a NEMA 4 washdown-protected AC inverter into the same space as our competitors' NEMA 1 control.

Small, But Powerful. Precise motor control — no matter how demanding the application — is available through direct command of over 80 operating parameters. E-trAC is the easiest inverter to program and operate — the 32-character "message center" is so informative that you may never have to refer to the operating manual again.



Communication Flexibility. In addition to the powerful keypad, our standard RS-485 serial I/O link allows total computer control. Two-way communication permits setup, monitoring, and operation of more than 30 inverters from wherever you desire.

Total Control. E-trAC puts you in control with such useful features as master/follower, custom displays, dynamic braking, 8 preset speeds, user parameter restore, removable keypad, and adjustable torque limit. Simple-to-add options that enhance flexibility include 115-Vac control signals, synchronous line transfer, fin-through chassis mounting kits, and encoder feedback.

Call Today. Find out for yourself why your best value in an AC drive is the E-trAC WFC Series AC Inverter. Contact T.B. Wood's Sons Company, Chambersburg, PA.

Phone: (717) 264-7161
FAX: (717) 264-6420
In Canada:
Phone: (519) 271-5380
FAX: (519) 271-3094

Wood's The quality endures

UL CSA PTDA

Circle 142

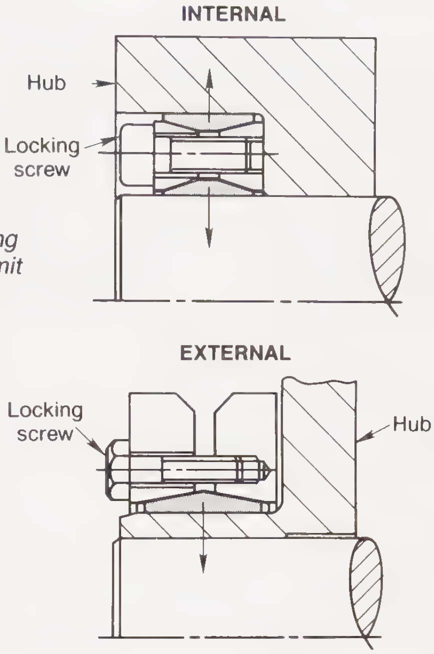
FRICTIONAL AND KEYLESS BUSHING

Fixing gears, pulleys, and other rotating elements to a shaft is done with a number of traditional techniques, and some more recent and versatile inventions. Traditional shaft to hub connections include splines, keyways, flats, setscrews, or press fits. But these require additional shaft and hub machining, or specialized mounting equipment. In addition, these methods produce stress risers that must be accounted for in sizing shafts. Typically, shaft size is larger than that needed to simply transmit the required torque.

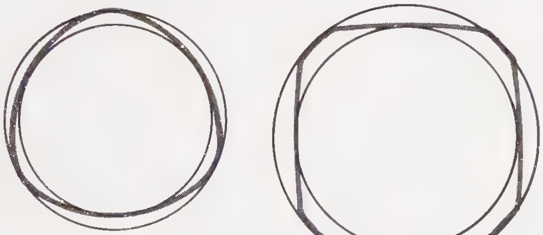
Admittedly, when loads are light, steady, and nonreversing, a key is the best and lowest-cost method for holding a hub to a shaft. But for heavy-duty applications, where loads reverse or shocks occur, keyless methods have advantages.

Frictional or keyless bushings handle shock and reverse loads, and often can be used over a damaged keyway. Other advantages include:

- No shaft machining required. Often, an unground shaft with a 125-μin. surface is sufficient.
- Shafts can be sized smaller than required for a keyway because stress risers are eliminated. Smaller shafts also allow downsizing other machine elements, such as bearings.
- Easy installation. A typical hub for a 3-in. shaft weighs about 5.5 lb.
- Easy relocation or removal. Loosening the device often disengages it from the shaft. Mounts that do not self-disengage have other features that make removal easier.
- They mount hubless elements. Thin elements, such as plate cams or chain sprockets, are mounted securely, with a minor torque reduction, but without having to weld a hub onto the element.
- Some designs allow overhung loads. Rigid shrink discs can carry the overhung loads of brakes or gearboxes to simplify equipment mounting.



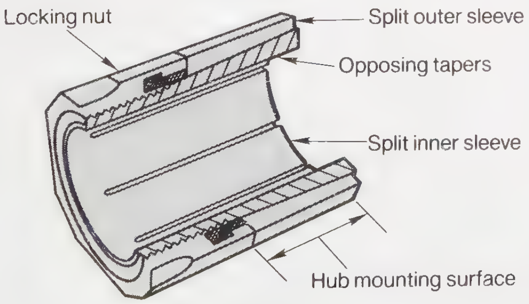
Shaft-hub locking devices are either internal or external. Internal units are used most often on general engineering applications to transmit high torque and axial loads using larger machining tolerance. External units are for high-torque transmission, particularly when external clamping is advantageous and better concentricity is required.



P3 POLYGON PROFILE

PC-R POLYGON PROFILE

One method for coupling shafts grinds a polygon shape onto a shaft end. This fits into a mating female hub with a similar shape formed by broaching or grinding.



ONE-NUT MECHANICAL SHAFT MOUNT

Six different designs are most often encountered. They generally operate by expanding an OD into a hub while reducing an ID onto a shaft. Three techniques are used to change diameters. One method uses opposing tapers; that is, a piece with a shallow incline is pulled over the shallow incline of another part. A split interior sleeve tightly squeezes around a shaft while a split exterior sleeve expands into hub.

The second method, also called a frictional hydraulic bushing, compresses a medium to expand a hollow sleeve. The third technique, called a clamping sleeve, changes diameters on a cross section that looks like an angular steel W.

Each design offers advantages that make it suitable for a particular set of requirements. For example, single-nut opposed-taper designs are the smallest. One model fits shafts as small as $\frac{3}{16}$ in. in diameter. A two-nut hydraulic bushing fits shafts as small as 0.236 in. (6 mm).

Furthermore, one and two-nut designs are self-releasing. This makes them well suited for applications where frequent circumferential or axial adjustments are necessary. For instance, a cam can be easily adjusted radially to change a timing function by loosening and tightening just one or two nuts.

A drawback with mechanical single-nut designs is the relatively high installation torque; 292 lb-ft for a 2-in. model to reach 1,167 lb-ft rated load. However, it may still be faster than tightening four to six bolts to lower torques on other models.

the sections on Mechanical Fixed and Adjustable-Speed Drives for a complete discussion.

Flat belts

Flat rubber belts were developed around the turn of the century primarily as replacements for leather belts. With the advent of V-belts, fewer machines were designed to use flat belts, and their production became largely a matter of supplying replacement parts.

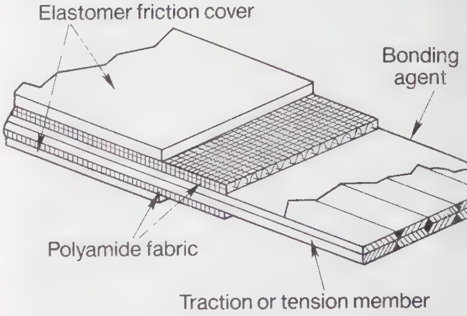
Recent developments in flat-belt technology have overcome their previous drawbacks of high tension and mistracking. New designs and advances in materials have made both low and high-power transmission practical and cost efficient, and at speeds that usually exceed other belt designs.

Small woven endless belts. This type of flat belt is used where minimum vibration is required at the driven pulley. For maximum damping, the spring rate of these belts can be tuned. In addition, semi-elastic belts have many features of unsupported stretch belts while maintaining a fabric substrate for support. The spring rate of these belts can be tuned to provide maximum damping. In addition, semi-elastic belts have many of the features of unsupported-stretch belts while maintaining a fabric substrate for support.

Semi-elastic belts do not require pulley take-up or adjustment, easily work in sets, work well over a wider length tolerance, and are relatively inexpensive in high volume. Because of these features, many OEMs are able to simplify and compact otherwise complicated designs. Over the past few years, the highest volume of semi-elastic belts have gone into machines for the banking industry, copiers, computer disk drives and peripherals, and office equipment. Most of these designs employ a wide variety of small multipulley precision drives.

Nonstretch endless flat belts also deserve consideration, especially in applications where small pulleys and/or high speeds (10,000 to 15,000 fpm) are involved.

ANATOMY OF A FLAT BELT



A flat belt's traction or strength member is usually made of extruded and bonded polyamide tapes. Polyamide fabrics are then bonded around the center to form the belt body. The final layer is a protective outer coating.

Because endless flat belts can be made very thin, 0.015 to 0.062 in., they are not as susceptible to centrifugal loads at higher speeds. Flat belts also are less costly than gears when teamed with small high-speed motors, especially when a compact package is important. Typical applications generally involve motors of 1 hp or less and speeds to 10,000 fpm.

Higher power flat belts. Developments here include sticky yet abrasion-resistant rubber compounds that eliminate the need for high tension to grip pulleys. These materials also allow lower shaft and bearing loads to transmit significant power. The strongest flat belts now transmit over 100 hp/in. of belt width.

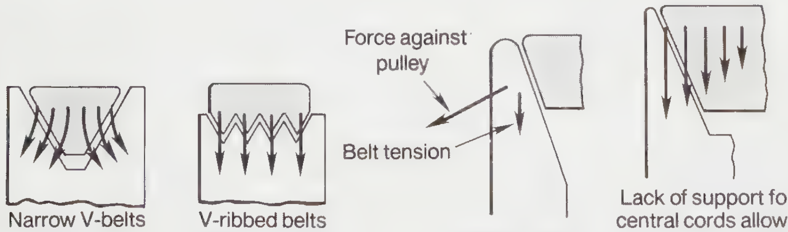
Different flat belt surface patterns serve different transmission requirements. For example, in high-power applications and outdoor installations, longitudinal grooves in the belt surface reduce the air cushion that flat belts generate when they run at speed onto a pulley. An air cushion reduces friction between pulley and belt. In addition, the longitudinal profile nearly eliminates the effect of dirt, dust, oil, or grease. Furthermore, the grooves reduce the noise level of an already quiet power transmission design even more.

Perhaps the most significant advantage of flat belts is their high efficiency — nearly 99%; about 2.5 to 3% better than V-belts. Good efficiency is attributed to three factors: lower bending losses due to their thin cross section, low creep because of special friction covers and high modulus of elasticity traction layers, and no wedging into

BELT GUIDE

Flat-belt drives need high belt tension to generate sufficient grip on the pulleys. V-belts are designed to wedge in the pulley, thereby multiplying the frictional force produced by tension and reducing the tension required for an equivalent torque. The wedging action, however, requires a clearance between the bottom of the belt and the pulley surface.

If the reinforcing cord in the belt is used effectively, each cord would be loaded to its design capacity. Cords located over the sloping wedge of the pulley are readily loaded by belt tension. But cords near the belt center, located over the portion of the section not in contact with the pulley, tend to sag inward, shedding load and contributing to inefficient use of the reinforcement. Maximum load capacity for a given width of belt therefore implies use of a deep, narrow section providing maximum support of the tensile cords. This concept led to development of narrow V-belts.



Narrow V-belts provide load distribution closer to an optimum

V-ribbed belts provide complete cord support but sacrifice wedging action

Wedging action multiplies force available to generate torque

Lack of support for central cords allows them to shed load, leading to less than optimum stress distribution

Total cord support is provided in belts bottoming completely on the pulley as in the flat, V-ribbed, and synchronous configurations. But except for the synchronous belt, complete contact requires additional tension for adequate grip. V-ribbed belts provide complete support with only a modest compromise in terms of additional tension. Synchronous belts provide complete support with virtually no tensioning requirements, but with other trade-offs largely involving cost.

WITH HABASIT'S
FLAT BELT TECHNOLOGY,
THE SKY IS YOUR ONLY LIMIT

INNOVATION IN DESIGN BEGINS WITH

YOUR IMAGINATION

Whether your new process or product design involves power transmission or linear motion, you'll appreciate the extra design freedom inherent in flat belt technology. Higher speeds, lower inertia and less energy consumption are just a few of the possibilities; lower maintenance and longer belt life, a few of the results. Find out how far no-sag, no-stretch, all synthetic belting can take your product designs.

Call Habasit today.

Habasit Belting, Inc. 3453 Pierce Drive PO Box 80507 Chamblee,
30366 Tel.(404)458-6431 Toll Free FAX 1-800-HABASIT

BELTMAN® simplifies belt calculations.
Ask for details.

habasit

INNOVATION IN MOTION

Circle 144

Habasit power transmission and conveyor belts

Habasit high efficiency flat belts are used as future-oriented machine elements in all branches of industry.

Habasit standard conveyor belts are suitable for all normal operating conditions.

Habasit offers simple joining systems: Thermofix, Flexproof and Quickmelt. If circumstances permit, belts can be joined directly on the machine. Downtimes are thus reduced and dismantling jobs are eliminated. All synthetic flat belts can be easily joined on-site using joining tools and methods supplied by Habasit.

Habasit manufactures according to quality standards ISO 9001/EN 29001, exclusively.

Habasit Belting Inc.
3453 Pierce Drive
P.O. Box 80507
Chamblee, GA 30366
Tel. 404-458-6431
FAX 1-800-HABASIT

INNOVATION IN MOTION

habasit

Circle 144

BELTING MATERIALS

Industrial belts and belting materials are usually reinforced rubber or leather. Nonreinforced types other than leather are limited to light-duty applications.

Rubberized fabric: This form of belting is the least costly. It consists simply of plies of cotton or synthetic fabric impregnated with rubber. For the same width and thickness, this type transmits less power and has a shorter life than leather.

Rubberized-fabric belts usually come in rolls and are cut to size and either bonded or fastened into a loop. But complete endless belts are also available. Both forms are limited to speeds below 6,000 fpm.

Rubberized cord: This type is available only as endless belts and is not designed to be spliced. Instead of being reinforced with fabric, it has rubber-impregnated cords running lengthwise, which improves strength (over the fabric type) by having the reinforcing material aligned with the tensile load. Cord-reinforced belts carry about 50% more power than fabric-reinforced belts. Maximum capacity is about 500 hp. This construction is rather "taut" and shock-absorption capacity is only fair.

Rubberized cord and fabric: The combination of both fabric and cord reinforcement provides the strength of cord reinforcement and the abrasion resistance of fabric. Single strand belts have a single layer of cords and are, thus, very flexible while being stretch resistant. Multiple-ply belts use several layers of cord reinforcement providing high tensile strengths. But these belts are not as flexible as the single-strand type and require larger pulleys.

They are well suited to serpentine drives and to applications where heavy shock loads are encountered. Numerous special variations of the fabric and cord design are available to meet such demands as minimum strength and high-speed operation.

Reinforced rubber or plastic: This type has a nylon or polyamide tensile member covered by rubber or elastomer. Capacities range from fractional horsepower to 100 hp per inch of width. These belts are capable of operating at 40,000 fpm.

Leather: Leather belts can carry significant loads — up to 500 hp — and can provide long service life. However, they are costly, they must be cleaned and dressed, and they are prone to stretch or shrink. They are normally limited to low or moderate speeds.

Fabric: These belts are made either plain or with chemical or rubber coatings. Their major feature is an ability to track uniformly.

pulleys like V-belts; hence, little body deformation. Without the V-beltlike wedging action, belt and pulley wear is minimal.

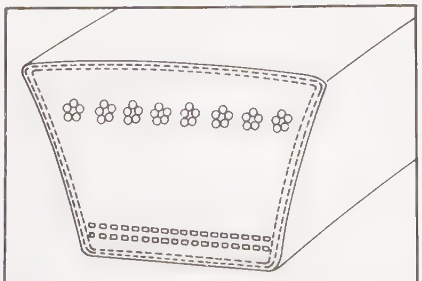
Flat belts offer greater design freedom than standardized designs because they are available in most any width and length, in increments of 1/16 in. This means drives can be sized closer to optimum rather than the next size larger.

Pulley alignment is equally important to flat belts as it is to other styles. Belt tracking is improved by crowning at least one pulley, usually the larger one. Flat belts are forgiving of misalignment; however, proper alignment improves belt life for any drive.

Low-horsepower drives with small pulleys are usually more expensive than comparable V-belt drives. But once the larger pulley reaches 30 in. in diameter, flat-belt drives become less expensive. Despite initial cost of smaller flat-belt drives, their efficiency gain makes up for the cost differential within a few years.

Classical multiple V-belts

In the early 1900s, industry used two types of belt drives: One employed the flat leather or fabric belt; the other was a system based on hemp or wire rope running in grooved pulleys in a manner similar to that of modern V-belts.



CLASSICAL V

These rope systems inspired development of the rubber V-belt, which first appeared in the 1920s. V-belts make use of a wedging action between belt and sheave, thereby developing high driving forces with considerably less belt tension than required by flat belts. This feature reduces loads on bearings. Also, V-belts inherently track better than flat belts and, thus, do not have to be aligned as carefully.

When V-belts first appeared, most applications were for large industrial drives typically requiring 10 to 15 belts between a single pair of shafts. Thus, belts for these industrial drives became known as "multiple" belts, and today they are referred to as "classical multiple" or "heavy-duty conventional" belts. V-belts and sheaves have been standardized, with letter designations running from A through E. These standard sizes are recognized worldwide.

Classical multiple V-belts offer the broadest range of power ratings and generally are the first type considered whenever a belt drive is being contemplated. They are readily available from local distributors and are engineered and rated for long, low-maintenance service. Virtually their only drawback when compared to more modern designs is relatively high weight and space requirements. The belt, being of heavy construction, generates high centrifugal forces that place relatively low limits on top speed. Also, the thickness of the belt limits bend radius, thus requiring the need for relatively large sheaves. In practice, these constraints rarely are serious limitations.

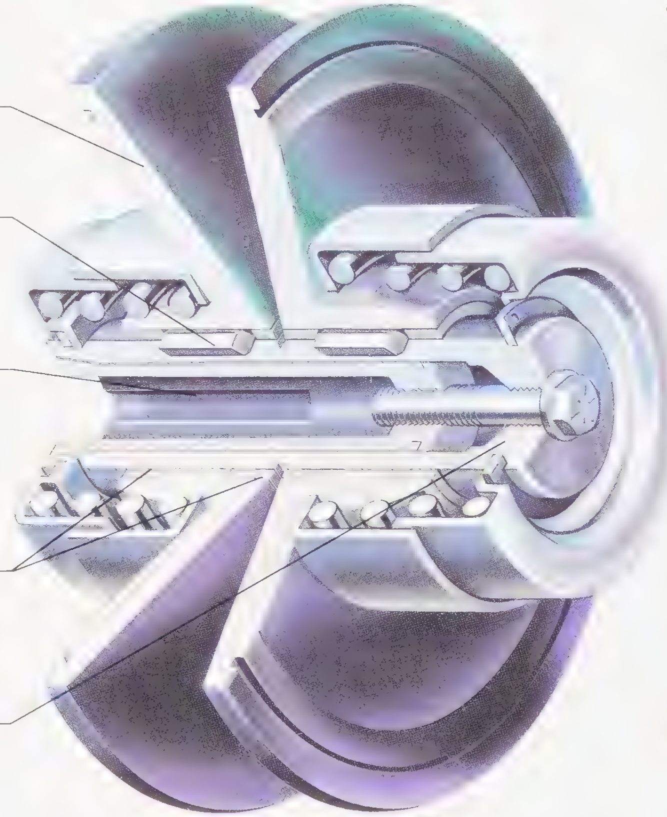
Most manufacturers offer two lines of multiple classical belts. One is the "standard" classification based on a fabric-wrapped construction. The wrap provides a protective envelope that tends to prevent damage and prolong life. The other classification is the "premium" or nonwrapped construction. The advantage of this design is that for a given standard size, none of the cross section is allocated to a wrap; thus, the total section consists of working tensile material. This allows belts of nonwrapped construction to be rated at higher power, section for section.

The lack of wrap makes a belt more vulnerable to damage; therefore, wrapped construction can be thought of as a more conservative selection. In OEM applications, however, service conditions tend to be well defined, and drive systems normally undergo thorough analysis and rigorous testing. Thus, these applications tend to favor nonwrapped construction, where the higher power rating can be used safely by virtue of the thorough engineering

GERBING

Variable Speed Pulleys

Quadra-Key™
3 to 30HP



Lightweight hard anodized aluminum discs provide low inertia, long life operation.

Resilient keys transmit torque from hub to disc. No fretting or corrosion. No maintenance.

Interchangeable collets. Provide simple installation and removal. Reduce inventory—one pulley provides several bore sizes.

NEW–Precision machined permanently lubricated metallic bushings provide long maintenance free life.

NEW–Push out hole provides easy pulley removal even after years of use.

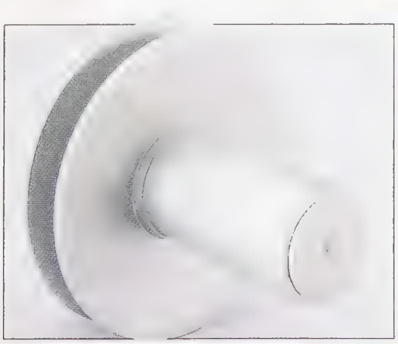
The broadest line of variable speed pulleys in the industry. Excellent prices. Same day delivery.

GERBING® drives offer the easiest and most economical method of providing a machine with infinitel variable speed control...instant, accurate, smooth and reliable.

GERBING® also offers a variety of manual, electric and remote controlled adjustable motor bases and companion sheaves, specifically designed for variabl speed applications.

Local service and stock availability. Our customers are served promptly through a nationwide network of more than 500 distributor outlets.

New! 25-30 HP aluminum models now available.



Roto-Cone

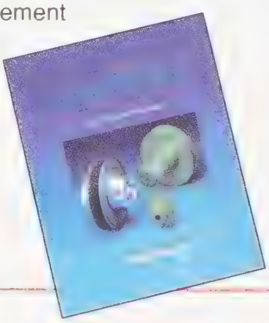
- 1/2 to 30HP
- Rugged cast iron construction.
- Years of proven reliability
- Horizontal or vertical operation
- Two disc movement

Var-A-Cone

- 1/2 to 1-1/2HP
- Economical, single disc movement.
- Through-shaft mounting.
- Maintenance free
- Rugged cast iron construction

Flexible Jaw Couplings

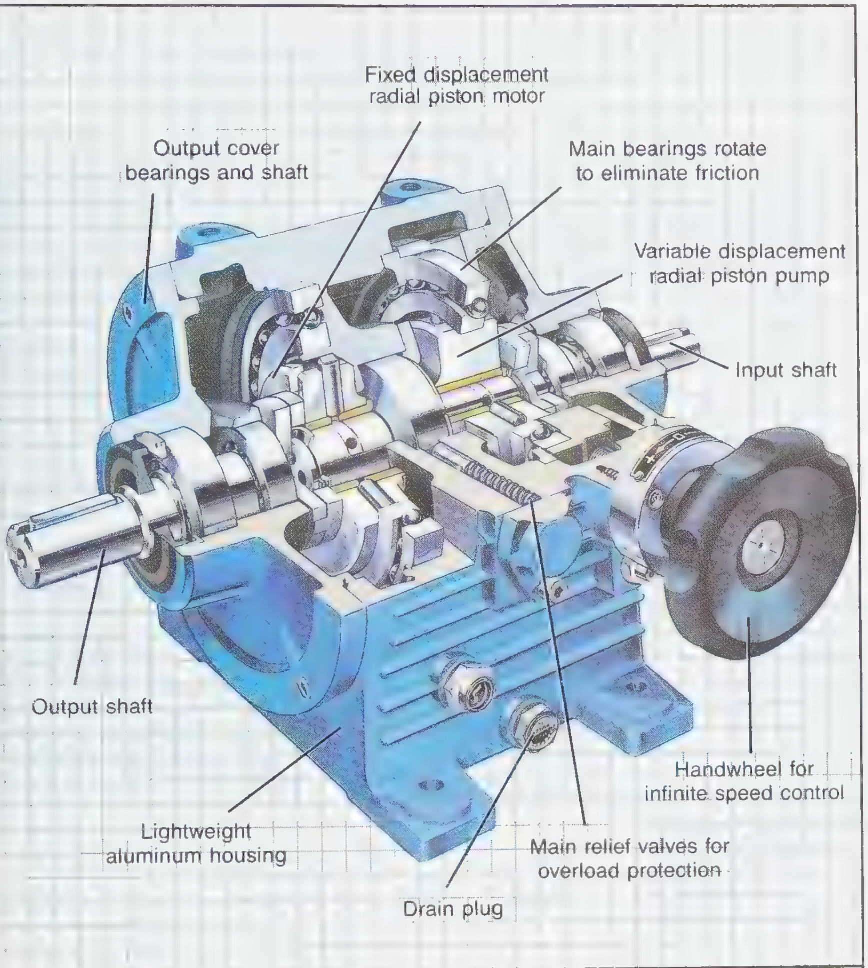
- Up to 7140 lb. in. torque capacity.
- Concave jaw design provides:
  - • Smooth operation
  - • Minimal backlash
  - • Long life
- Elastomeric element

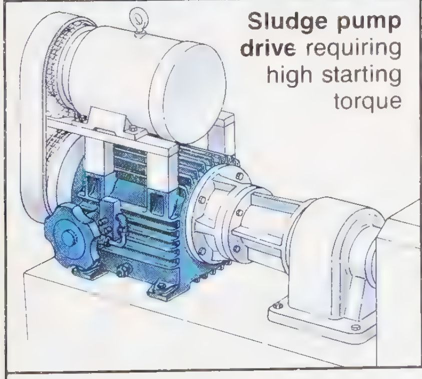


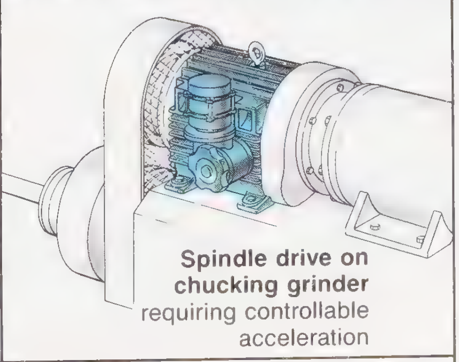
Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog P-1013
815/389-3771 • Fax 815/389-2582

WARNER ELECTRIC
DANA

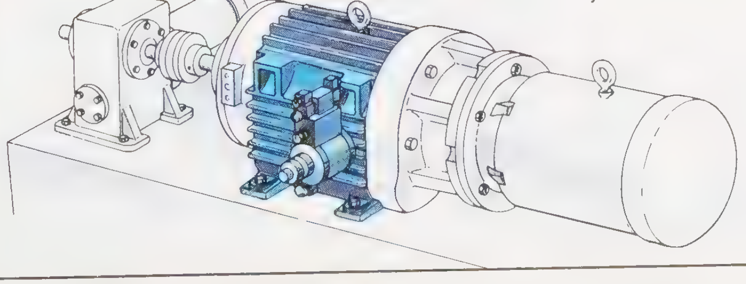
FORMSPRAG® HSV hydrostatic speed variators . . . rugged, precise control, high performance, wide speed range


Fixed displacement radial piston motor
Output cover bearings and shaft
Main bearings rotate to eliminate friction
Variable displacement radial piston pump
Input shaft
Output shaft
Handwheel for infinite speed control
Lightweight aluminum housing
Main relief valves for overload protection
Drain plug


Sludge pump drive requiring high starting torque


Spindle drive on chucking grinder requiring controllable acceleration

Pipe coating machine bi directional operation, high starting torque and jerk free acceleration



1. High Performance
The Formsprag HSV is an integrated hydrostatic transmission featuring high starting torque, precise controllable acceleration and bi-directional operation. 9 standard models from 1/2 HP to 30 HP.

2. Easy-to-control
21 different controls in 5 basic types: manual, electric remote, pneumatic proportional, electrohydraulic remote and servo controls.

3. Rugged
Formsprag HSV drives are heavy duty, totally enclosed units ideally suited for abrasive dust, washdown and explosion proof environments.

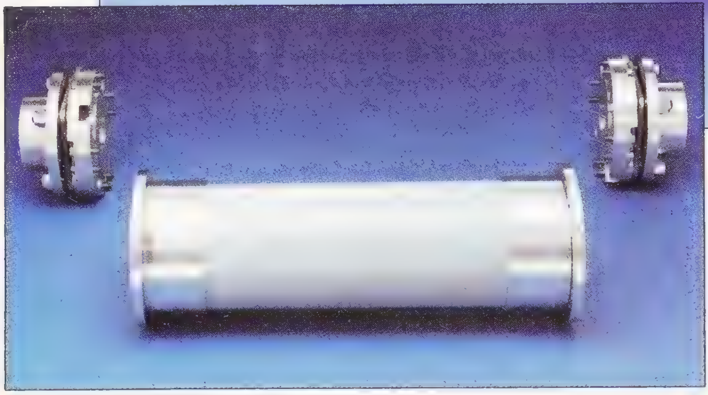
4. Convenient mounting flexibility
Available as a stand alone, foot mounted unit or with NEMA-C flanges. For your convenience, the complete package with an electric motor and reducer can be furnished by Formsprag.

5. Local service and stock availability
Our customers are served promptly through a nationwide network of more than 500 distributor outlets.

Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog P-933
815/389-3771
Fax 815/389-2582

WARNER ELECTRIC
DANA

Span The Performance Gap With FormFlex Cooling Tower Couplings.



- Pre-assembled flex pack that contains no loose parts.
- 4-Bolt design permits for 1° of misalignment per flex element.
- Maintains balance after repeated assembly and disassembly

With our new FormFlex Cooling Tower Dropout Spacer, you get a factory assembled three piece unit instead of a multitude of parts to drop or lose.

The unit consists of two flexing assemblies which include the hub, flex packs and all hardware, plus the dropout spacer. The 4-bolt design allows for 1° misalignment per flex element, 30% more than any other cooling tower coupling.

The dropout spacer design ensures your coupling maintains its precision balance after repeated assembly and disassembly. Available in lengths up to 20 ft. with no center bearing to maintain.

Span the performance gap with FormFlex Cooling Tower couplings. Call us today and ask about our new dropout spacer or any other of our full line of cooling tower couplings.

2401 Interstate 35
San Marcos, TX 78666
Customer Service: 512-353-4000
Fax: 512-353-4017

FORMFLEX

DANA

Circle 148

applied to possible environmental effects on the belt.

Belts for in-plant use, in contrast, are normally selected according to simple catalog ratings or to fit existing sheaves. Little, if any, attention is given to life testing or environmental effects, so wrapped construction is recommended.

Belts of nonwrapped construction, sometimes called bandless or raw-edge belts, are made with cogs or molded notches on the underside. Cogged belts permit more severe bends, thus allowing operation over smaller pulleys. Belts of standard wrapped construction are not available cogged because the protective envelope is both difficult to manufacture in cog form and also prevents severe bends. Notched belts are more expensive than those having a flat base. However, because they have a higher load-carrying capacity and run on less-expensive, smaller-diameter pulleys, the drive may require fewer notched belts.

Classical V-belts are frequently used individually, particularly in A and B sizes, smallest of the five cross sections. The larger sections, C, D, and E, generally are not used in single-belt drives because of certain cost penalties and inefficiencies encountered when scaling drives upward. The economics are such that for equivalent ratings, multiple belt drives based on A or B sections usually cost less than single-belt drives with C, D, or E sections.

Single V-belts

Although classical V-belts can be used individually, classical belts tend to be somewhat overdesigned for drives light enough to demand only one belt. Thus, a special category of belts evolved specifically for single-belt applications, with the terms "single belt," "fractional horsepower" (FHP), or "light duty" denoting this class.

Originally, these belts were developed to serve the needs of OEM consumer applications such as furnace blowers, lawn and garden equipment, and home shop tools. The belts were generally custom designed for each application, but as replacement markets developed, the sizes were standardized. Designations run from 2L (the smallest) to 5L (the largest). The 4L and 5L sections were dimensionally similar to A and B classical belts and can operate interchangeably on A and B sheaves. However, 4L and 5L belts have a lower power rating than classical A and B section belts. The 4L and 5L were originally termed FA (fractional A) and FB (fractional B), and 3L was formerly called FO.

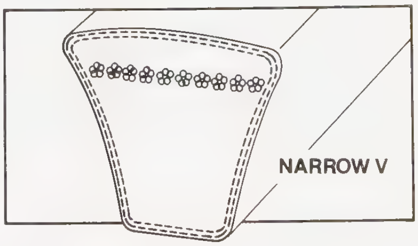
Classical V-belts are the backbone of industrial drives. Most manufacturers offer a standard line rated for fractional horsepower and intended for mass-produced products such as furnace blowers, small tools, and other consumer-oriented applications. Belts are also manufactured to special order for appliances and lawn and garden equipment where the need for maximum performance at lowest cost justifies extensive design and development.

The service life provided by standard single-belt sections often far exceeds that demanded by low duty-cycle consumer equipment. Thus, life can be traded off for the sake of higher power rating. In this way, fractional-horsepower belts can be used to transmit more than one horsepower. For example, up to 10 hp can be transmitted by a single belt if a service life of under 1,000 h is acceptable. This practice is common with lawn and garden equipment where belt life is designed for hundreds of hours of service rather than thousands of hours in continuous industrial applications.

If the life sacrifice is too great, the belt can be made more durable through special construction and choice of reinforcing materials. Most manufacturers offer such designs as "premium" stock belts intended primarily for lawn and garden replacement service. But the belts also may be used to extend the life of any single-belt drive.

Narrow V-belts

V-belts in classical and single-belt configurations are not optimum from the standpoint of load transfer. Reinforcing cords near the center of the belt sink radially inward under tension, thereby shedding load and reducing the total power capacity of the belt.



Narrow belts overcome this deficiency through a configuration having greater depth to width ratio, thereby placing more of the sheave directly under the reinforcing cord. Thus, loads in the tensile cord are transferred more directly to the sides of the sheave, allowing minimum load shedding and producing better force distributions. For a given width, narrow belts therefore have power ratings much higher than those of conventional V-belts. The improvement in load-carrying capacity becomes more pronounced with

SHEAVES AND PULLEYS

Most sheaves for industrial use are cast iron and are generally limited to 6,500 fpm for narrow belts and classical belts. For lighter service, sheaves may be made of stamped steel or aluminum, plastic, or die-cast aluminum or zinc. Aluminum, steel, and ductile-iron sheaves can be used at various speeds as specified by the supplier.

Sheaves are made with either regular or deep grooves. Deep grooves are normally used when the belt must enter the sheave off-axis.

Some sheaves come with removable hub bushings to allow change in bore size or to provide for easy installation and removal of sheave and belt. Sheaves are statically balanced by the manufacturer, but those to be used at high speed should be dynamically balanced.

Some means must be provided to keep a flat belt riding true on the pulley. This can be done by putting either flanges or a crown on the pulley. Crowning is preferred, but it must be limited to prevent undue stress concentration in the middle of the belt. Maximum recommended crown is ⅛ in.

Crowning should be less for belts reinforced with high modulus materials such as steel or glass cable. For pulleys under 10 in., 3/64 in. is usually sufficient.

No crown is needed on pulleys used for belt take-up. But idler pulleys should have crowning. Idler pulleys should be as large as possible to minimize reverse flexing. Outside idlers should be about 30% larger than the smallest drive pulley.

For belts up to 6 in. wide, pulleys should be 1 in. wider than the belt. Over 6 in., the pulley should be 2 in. wider. If a drive can be perfectly aligned, however, the pulley need be no larger than the belt.

Pulleys for ribbed belts must be mated to the particular belt used. Synchronous pulleys are never crowned, so at least one pulley in a synchronous drive must be flanged to keep the belt tracking properly.

DODGE

DODGE® TAPER-LOCK® BUSHING SHAFT MOUNTING SYSTEM

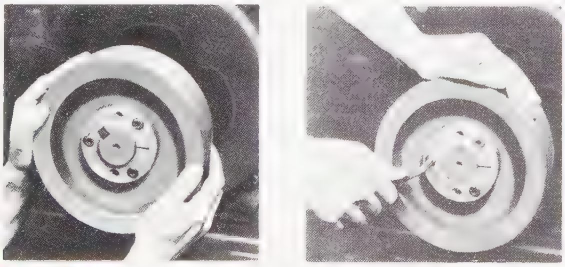
DRIVE COMPONENT DATA SHEET

Shaft Mounting Made Easy

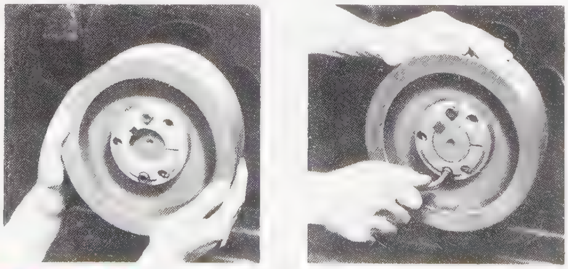
Mounting sheaves, sprockets, couplings, gears, fan impellers, flywheels, pulleys and clutches properly and securely to a shaft is no easy task until you use DODGE TAPER-LOCK Bushing Systems. Competitively priced TAPER-LOCK bushings actually wedge the component tightly onto the shaft without the use of shaft-marring setscrews or expensive shrink-fit methods.

This strong "wedge" results from installation force developed at the screws in mated half-holes in the outer diameter of the bushing and in the inner diameter of the component or hub bore. The half-holes in the hub are threaded so that when the installation screws are tightened, the split tapered bushing is forced into the tapered bore, causing it to contract evenly about the shaft.

In addition, the TAPER-LOCK system of bushings and products provides interchangeability, so you can save on inventory. TAPER-LOCK bushed components can be used on a variety of shaft sizes merely by changing the bushing. Different components such as sheaves, sprockets, couplings and pulleys may also be interchanged using stock TAPER-LOCK bushings of various common bore sizes. Non-standard bore sizes are also available on special order.



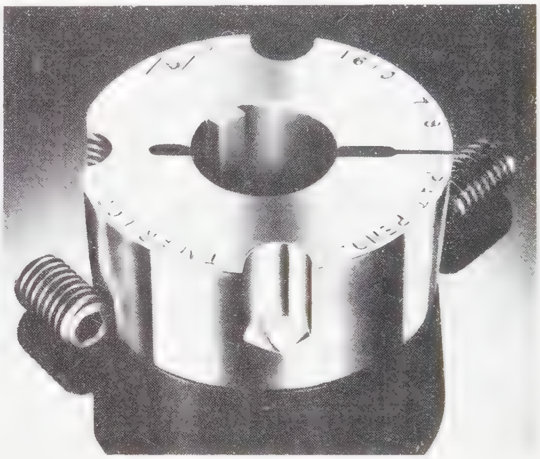
Easy On *Insert bushing in hub. Match holes (not threads) and slip entire unit onto shaft. Put screws into the holes that are threaded in hub only. Align the product and tighten screws. As bushing is wedged inward, it contracts — evenly — and grips the shaft.*



Easy Off *Take the screws out entirely, insert them into the holes which are threaded in the bushing only using them as jack-screws. This disengages the bushing. Its grip is "unlocked," permitting quick, easy removal of product. Note: For complete instructions, refer to instruction sheet packaged with each bushing.*

DIAMOND ⟨D⟩ Bushings with Integral Key Popular Bore Sizes in Type 1008 to 2717.

The most significant innovation in the 40-year history of tapered bushings.



CONVENIENCE

Just think of the time you'll save in installation, maintenance and downtime. No more loose keys. No more setscrews. No vertical shaft application problems. No more lost keys.

IMPROVED RELIABILITY

Because the DIAMOND ⟨D⟩ Integral Key is part of the bushing, it cannot work loose and fall out as with separate key installations. This is especially important on vertical shaft applications. Clearances between key an bushing are automatically eliminated, providing a more precise fit. Key wobble on reverse load applications is eliminated. And there is no concern over a "forgotten" key.

Easy on – Easy off TAPER-LOCK with Integral Key. Fewer parts to install, manipulate or lose.

COST REDUCTION

With DODGE DIAMOND ⟨D⟩ Integral Key, there is no separate key to purchase and inventory. Labor cost savings result; there is no separate key to install and secure with a setscrew.

DODGE

TAPER-LOCK BUSHINGS

ush lo.	Fig.	Max. Bore	Ratings ◆ Bush Torque Capacity Lb-In	Ratings Install Wrench Torque Lb-In	A	B	C: Req'd. Hub Dia. Class 20 Gray Iron	C: Req'd. Hub Dia. Class 30 Gray Iron	C: Req'd. Hub Dia. Steel	D	Install/ Removal Screw Data † Qty.	Install/ Removal Screw Data † Size	L ● Std. Hex Key	L ● Short Hex Key	H ★ Std. Hex Key	H ★ Short Hex Key
008	1	1	1,200	55	1.386	0.87	2.37	2.19	1.93	1.33	2	$\frac{1}{4} \times \frac{1}{2}$	1.12	0.62	1.25	0.75
108	1	$1\frac{1}{8}$	1,300	55	1.511	0.87	2.50	2.31	2.06	1.45	2	$\frac{1}{4} \times \frac{1}{2}$	1.12	0.62	1.25	0.75
210	1	$1\frac{1}{4}$	3,600	175	1.875	1.00	3.67	3.25	2.87	1.75	2	$\frac{3}{8} \times \frac{5}{8}$	1.37	0.81	1.62	1.06
215	1	$1\frac{1}{4}$	3,550	175	1.875	1.50	3.12	2.87	2.62	1.75	2	$\frac{3}{8} \times \frac{5}{8}$	1.37	0.81	1.62	1.06
310	1	$1\frac{7}{16}$	3,850	175	2.000	1.00	3.75	3.37	3.00	1.87	2	$\frac{3}{8} \times \frac{5}{8}$	1.37	0.81	1.62	1.06
610	1	$1\frac{11}{16}$	4,300	175	2.250	1.00	4.00	3.62	3.25	2.12	2	$\frac{3}{8} \times \frac{5}{8}$	1.37	0.81	1.62	1.06
615	1	$1\frac{11}{16}$	4,300	175	2.250	1.50	3.50	3.25	3.00	2.12	2	$\frac{3}{8} \times \frac{5}{8}$	1.37	0.81	1.62	1.06
012	1	$2\frac{1}{8}$	7,150	280	2.750	1.25	4.75	4.37	3.87	2.62	2	$\frac{7}{16} \times \frac{7}{8}$	1.56	0.94	2.00	1.37
517	1	$2\frac{11}{16}$	11,600	430	3.375	1.75	5.50	4.87	4.37	3.25	2	$\frac{1}{2} \times 1$	1.62	1.00	2.25	1.62
525	1	$2\frac{11}{16}$	11,300	430	3.375	2.50	4.75	4.50	4.25	3.25	2	$\frac{1}{2} \times 1$	1.62	1.00	2.25	1.62
020	1	$3\frac{1}{4}$	24,000	800	4.250	2.00	7.00	6.25	5.62	4.00	2	$\frac{5}{8} \times 1\frac{1}{4}$	1.81	1.18	2.69	2.06
030	1	$3\frac{1}{4}$	24,000	800	4.250	3.00	6.25	5.75	5.37	4.00	2	$\frac{5}{8} \times 1\frac{1}{4}$	1.81	1.18	2.69	2.06
535	2	$3\frac{15}{16}$	44,800	1,000	5.000	3.50	7.75	7.00	6.50	4.83	3	$\frac{1}{2} \times 1\frac{1}{2}$	2.00	1.31	3.37	2.69
040	2	$4\frac{7}{16}$	77,300	1,700	5.750	4.00	9.50	8.50	7.75	5.54	3	$\frac{5}{8} \times 1\frac{3}{4}$	2.37	1.62	4.12	3.37
545	2	$4\frac{15}{16}$	110,000	2,450	6.375	4.50	10.50	9.50	8.75	6.13	3	$\frac{3}{4} \times 2$	2.62	1.94	4.75	4.06
050	2	$5\frac{5}{16}$	126,000	3,100	7.000	5.00	11.50	10.50	9.50	6.72	3	$\frac{7}{8} \times 2\frac{1}{4}$	2.81	2.31	5.25	4.81
050	3	6	282,000	7,820	9.250	5.00	17.00	17.00	15.50	13.50	3	$1\frac{1}{4} \times 3\frac{1}{2}$	1.62	1.62	4.37	4.37
060	4	7	416,000	7,820	10.250	6.00	18.50	18.50	17.00	14.75	4	$1\frac{1}{4} \times 3\frac{1}{2}$	1.62	1.62	4.37	4.37
065	4	8	456,000	7,820	11.250	6.50	19.00	19.00	17.50	15.50	4	$1\frac{1}{4} \times 3\frac{1}{2}$	1.62	1.62	4.37	4.37
085	4	10	869,000	13,700	14.750	8.50	23.50	23.50	22.00	19.50	4	$1\frac{1}{2} \times 4\frac{1}{4}$	2.00	2.00	5.37	5.37
0100	5	12	1,520,000	13,700	17.250	10.00	28.00	28.00	26.00	23.00	6	$1\frac{1}{2} \times 4\frac{1}{4}$	2.00	2.00	5.37	5.37

e: For dimensions required for machining hubs, consult ory.

nportant: Refer to service factor information on page D1-5.

pace required to tighten bushing. Also space required to osen screws to permit removal of hub by puller.

★ Space required to remove bushing using jackscrews—no puller required.

† Use in position shown in drawing below for tightening bushing on shaft. When loosening bushing, remove screws and use all except one in the other holes.

Bushing No.	G
3535	39°
4040	40°
4545	40°
5050	37°

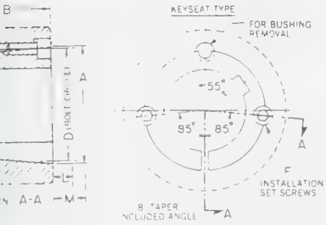


Fig. 1

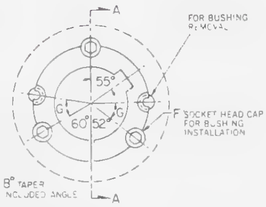


Fig. 2

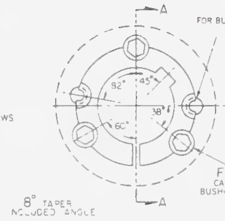


Fig. 3

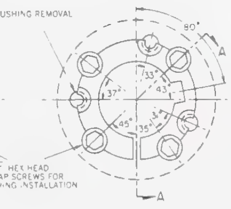


Fig. 4

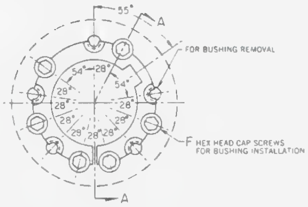
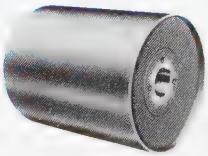


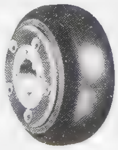
Fig. 5

TAPER-LOCK Bushings Used in All of These Quality Products

Roller Chain rocket

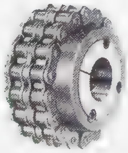


Conveyor Pulleys



Flexible Cushion Couplings

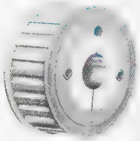
Rigid Couplings



Chain Couplings

V-Belt Sheaves

Flexible Disc Couplings



Synchronous Pulleys

Specify DODGE TAPER-LOCK®
Move faster with the leader.™

OGE / P.O. Box 499 / 2 Ponders Ct. / Greenville, S.C. 29602-0499 / 803-297-4800 / FAX: 803-297-2318

eliance Electric Company, 1990

Circle 149

RELIANCE ELECTRIC

DODGE* made... Quality QD* sheaves and bushings.

QD sheaves and bushings built to DODGE high standards:

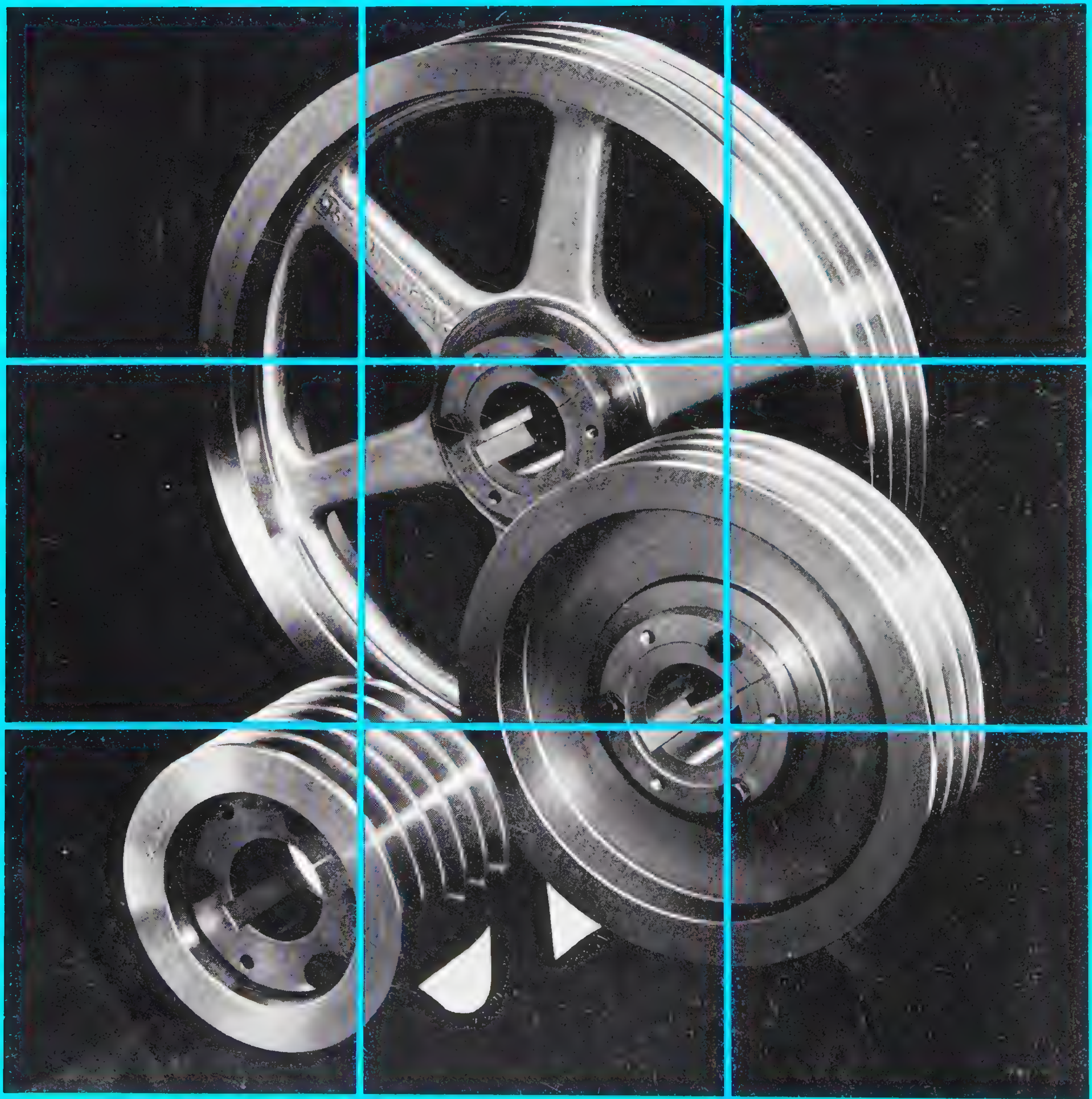
- **Custom-metallurgy for maximum strength and durability.**
- **Precision machined and balanced for top performance.**
- **Standard dimensions for industry-wide interchangeability.**
- **Conventional and reverse mounting.**

DODGE sheaves and bushings. Unmatched in quality and performance. Sheaves sizes 2.65" to 5.75" O.D. in sintered steel with allowable rim speeds to 10,000 FPM. Sizes 6.0" to 71.0" in industry standard cast iron. QD bushing sizes JA to SF in sintered steel and sizes E thru W in cast iron.

Specify DODGE Sheaves and Bushings.

DODGE®

Move with the leader.™



For more information call (803) 297-4600, FAX (803) 281-2318. Or see your local DODGE Distributor in the Yellow Pages.

RELIANCE ELECTRIC

*QD is a registered trademark of Emerson Electric Company

Circle 150

increases in the strength of the reinforcing cord.

Narrow belts have been standardized, with designations being 3V, 5V, and 8V. Some belts are cogged to maximize the allowable degree of bend, thus permitting operation over small pulleys and allowing space-saving design. These belts represent the highest level of development of V-belts. The space saving they allow is significant, especially in high-reduction drives. In all, they provide the highest power in the smallest package and are particularly well suited to severe duty applications, including those subjected to shock and high starting loads.

V-ribbed belts

The V-ribbed concept combines some of the best features of flat belts and V-belts. It employs what is essentially a flat belt with a series of V-shaped ribs running the length of the belt on the driving surface. The belt, being thin, operates efficiently and can be run at high speed. But even more important, tensile cords have total support because the belt ribs bottom completely on the sheave; there is no wedging action. The total support of the cord permits high load-carrying capacity, and theoretically this design could provide the highest capacity of any belt if reinforced with high-strength fiber. To date, however, there has been no commercial demand for such exceptional power capacity in this type of belt.

The sacrifice of wedging action in V-ribbed belts increases tensioning requirements, but not to the levels required by flat belts. Supposedly, friction is independent of area of contact. Nevertheless, the V-ribbed shape does increase friction between belt and sheave considerably beyond that of flat belts. Consequently, tensioning requirements are only about 20% above those of V-belts. In addition, the ribs ensure that belts track properly, making alignment less critical than it is for flat belts. Alignment requirements, however, are more critical than those of V-belts.

Major applications of the V-ribbed belts are in mass-produced consumer goods such as snow blowers, home power tools, and clothes dryers. It is also used for accessory drive in some automobiles. Operating efficiency of the V-ribbed belts rivals that of flat belts and synchronous belts. It also is able to operate over small pulleys. Because it is available in small width increments (of one-rib width), belts can be matched almost precisely to the power requirements of specific drives. V-ribbed belts are not recommended for clutching drives.

The belt performs well with reverse-bend idlers, and most applications involve high-speed ratios with a reverse-bend idler being employed for take-up and to increase the arc of wrap on the smaller pulley.

Five standard configurations are available, with designations of H, J, K, L, and M. L and M were the first to be introduced and are intended primarily for industrial and agricultural drives. The M section is capable of transmitting up to 1,000 hp. J (originally called JR) is normally applied to fractional-horsepower drives in home appliances, snow blowers, and power tools. H is intended for miniature drives and K for automotive accessory drives.

The V-ribbed section, because it is available in extremely high-power ratings, eliminates matched-set belts required in multiple V-belt drives. The power density also permits compact drive configurations.

The most effective use of V-ribbed belts normally demands engineering design and testing of the drive system. Some tooling investment may be necessary for pulleys. The user also may find it prudent to draw upon the belt manufacturer for technical help and design refinement. Therefore, the V-ribbed concept is almost always applied to mass-produced drives.

Joined V-belts

Pulsating loads, such as those generated by internal combustion engines and compressors, present special problems for V-belt drives. Intermittent forces tend to produce a whipping motion in the belts which, in the worst case, causes them to turn over in the pulley grooves. It is often said that the worst possible drive from this standpoint is a compressor driven by a diesel engine.

Because high-power drives of this type employ multiple belts, a solution to the problem is to join the belts by a top band, fusing them into a single broad belt immune to turnover. The basic belt element can be either classical or narrow. The joined configuration also avoids the need to order multiple belts as matched sets.

In a sense, joined V-belts are similar to the V-ribbed configuration. V-ribbed belts, however, require special sheaves, often not available from stock. Joined V-belts, in contrast, often are preferred because they fit on stock sheaves and can operate interchangeably with standard matched sets.

Anyone using joined V-belts should ensure that they are not mounted on deep-groove sheaves, which sometimes are employed to minimize alignment problems or to avoid turnover in standard V-belts. Such sheaves have the potential for cutting the band of a joined belt. Extremely worn sheaves can produce a similar effect.

Another important feature of joined narrow belts is their ability to take advantage of high-strength tensile cords. Joined 5V and 8V belts are available with aramid-fiber reinforcement.

Link belts

A modular approach to PT belts is used by link belts. The link, a composite of textile plies of urethane, is connected to adjacent links by a rivet or spade end twisted through the next link. In this manner, belts of almost any length can be made. Older link-belt materials had to be derated when directly replacing an endless belt. However, new materials and designs allow replacement without any derating.

Link belts are generally available in A, B, and C widths in 100-ft lengths. The latest generation of this belt type with its rivetless construction and urethane/polyester-plied construction transmit the full horsepower of classical V-belts. The major advantage of link belts is downtime reduction. Matched sets of the correct length belt are always on hand. Because the belt can be joined on the machine, it can often be installed much faster than a conventional V-belt. Other advantages include improved oil and water resistance, vibration damping and an extended temperature range.

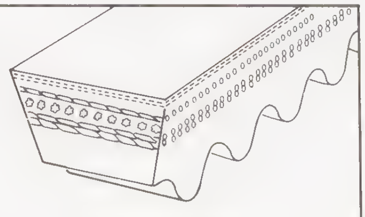
Disadvantages are that newer materials may be more expensive, but older designs and materials did not transmit the same power as endless V-belts. Some materials may generate static charges and should be used only on grounded equipment in high-dust areas.

Synchronous belts

The potential for slip in conventional belts prevents their use where input and output shafts must be synchronized. Synchronous belts, often referred to as timing belts, were developed to overcome this limitation. They have a toothed profile that mates with corresponding grooves in the pulleys, thereby providing the same positive engagement of chain or gears.

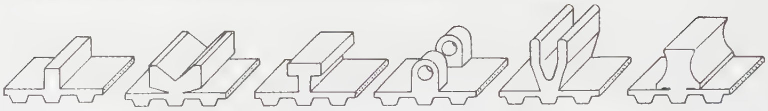
A stable belt length is critical for synchronous applications, so they were originally reinforced with steel. Today the most common reinforcement is glass fiber, but aramid is used if maximum capacity is required. Standard sections are MXL, XL, L, H, XH, and XXH.

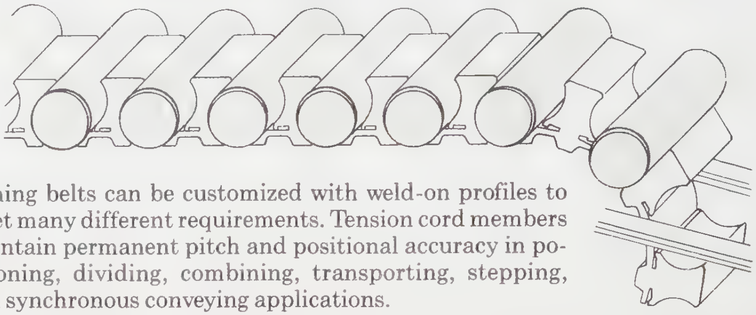
The first tooth profile used on synchronous belts, and a profile still recognized as standard, is of trapezoidal shape. Belts with this configuration are commonly used in machine tools, textile machinery, home appliances, business equipment, and as camshaft drives in engines.



SYNCHRONOUS

WELD-ON PROFILES FOR SYNCHRONOUS CONVEYING





Timing belts can be customized with weld-on profiles to meet many different requirements. Tension cord members maintain permanent pitch and positional accuracy in positioning, dividing, combining, transporting, stepping, and synchronous conveying applications.

Stock profiles are available to solve specialized functions in automation and conveying. Standard or custom-tooled profiles, with and without inserts, allow adaptation of profiled timing belts to particular applications or equipment. Profiles can be mechanically modified by drilling, milling, cutting, and grinding. Attachments may be added. The molded or machined profiles are thermally attached to the polyurethane belt cover for a durable bond.

Synchronous belts have a number of attractive features that put them in applications where there is no real need for shaft synchronization. They are thin and flexible, so they operate well on miniature drives and in applications involving high speeds or small pulleys. Preliminary studies indicate that they may be the most efficient form of power transmission short of direct drive. In addition, they are able to sustain high loads. For these reasons, synchronous belts have proved to be cost effective in such nonsynchronous applications as drives for power saws, motorcycles, and vacuum-cleaner brushes.

The primary drawbacks of synchronous belts are their higher cost relative to other types, and a demand for fairly accurate alignment of pulleys. In all, synchronous belts can be used on highly engineered and mass-produced drives, and continue to be popular in general industrial markets.

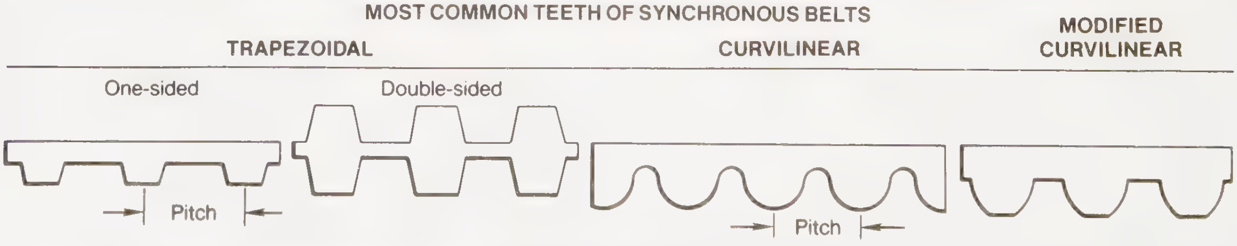
Recent modifications to tooth profiles have improved on the original trapezoidal shape. The full-rounded profile, often called HTD, distributes tooth loads more evenly to the belt tensile member. It also provides greater tooth shear strength and hence carries greater load than trapezoidal designs.

A modified curvilinear tooth design is called STPD, and is similar in appearance to the HTD design. However, its pressure angle, tooth depth, and materials are chosen for improved load/life capacity and other characteristics such as nonratcheting. A newer, modified curvilinear tooth design is called GT. MXL pitch belts have recently been developed mainly to convey paper past reading heads at constant speed. A high-friction coefficient polyurethane is used in order to drive the paper with zero slip.

Some nonstandard belt pitches for special industrial use are sized between XL (0.20 in.) and L (0.375 in.) such as 0.233, 0.246, and 0.250 in. In the auto industry, new belts are designated STA, AL, and ZA. Main difference between industrial and automotive sections is the size and tensile cord, which changes the pitch line differential. Automotive and industrial belts are not interchangeable.

Dual-sided drives

Some unusual machinery configurations are best served by belts able to deliver power from both top and bottom surfaces. Drives employing such belts are referred to as dual drives. Flat belts inherently can serve in dual drives, provided that the wrap around each pulley is adequate. V-belt configurations generally must be manufac-



Pitches available

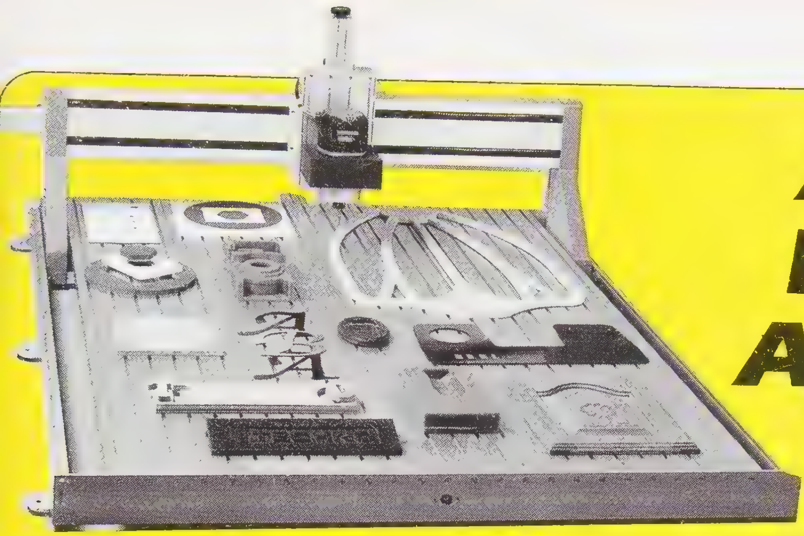
0.08 in, 0.2 in
0.375 in, 0.5 in
0.875 in, 1.25 in

0.2 in, 0.375 in
0.5 in

3 mm, 5 mm, 8 mm
14 mm, 20 mm

2.5 mm, 4.5 mm
8 mm, 14 mm

The trapezoidal tooth is the most common synchronous belt and can be the least expensive in some applications. Double-sided belts can engage and turn sprockets in either direction. The curvilinear design can carry higher loads because it has a deeper tooth and stronger tensile member.



Affordable Production Automation

Call for your *FREE* 168-page Techno Catalog H800 today.

516-328-3970

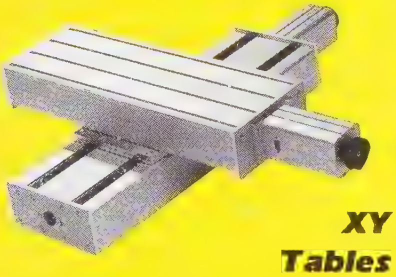
Introducing Series III Gantry XYZ Tables With Patented Linear Bearings

☐ Ball screw drive with stepper or servo motors.
☐ Available in 6 sizes from 13.8"x11.4" to 49.3"x41".
☐ Optional spindles and clamping components.

NEW!

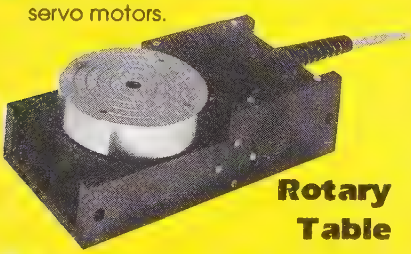
Series I Gantry Tables

☐ Ball screw drives with stepper or servo motors.
☐ Available in 5 sizes from 9.8" x15.7" x 4" to 48" x 48" x 4".



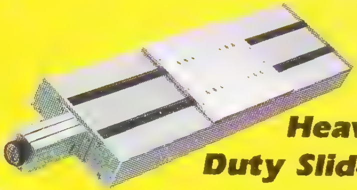
XY Tables

☐ All standard and heavy duty tables can be combined to provide XY travel up to 50" x 50".
☐ Ball Screw drive with stepper or servo motors.



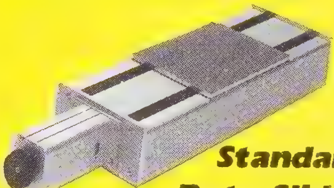
Rotary Table

☐ 5" diameter rotary table.
☐ Load capacity up to 2,000 lbs.



Heavy Duty Slides

☐ Available in 10 travel lengths from 4" to 47".
☐ Ball screw driven with stepper or servo motors. Load capacity to 250 lbs.

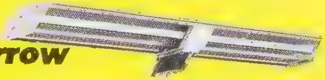


Standard Duty Slides

☐ Available in 10 travel lengths from 4" to 47".
☐ Ball screw driven with stepper or servo motors. Load capacity to 212 lbs.

Narrow Profile Stages

☐ Stocked in 10 travel lengths from 4" to 51".
☐ Ball screw driven with servo or stepper motors. Load capacity to 50 lbs.

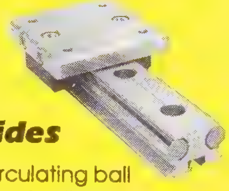


Narrow Profile Belt Drive

☐ Available in 4 travel lengths from 12" to 70".
☐ HTD Belt drive with stepper or servo motor drive. Load capacity to 50 lbs.

Ball Screws And Nuts

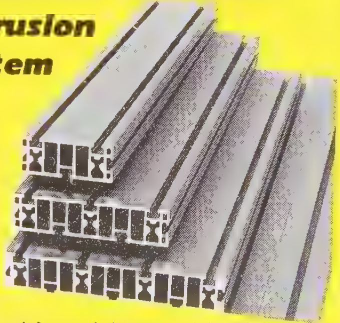
☐ Available with machined ends in 14 lengths to 70 inches. Unmachined lengths to 12 feet.
☐ Available in 5, 10, and 20 mm pitches.



Double Rail Linear Slides

☐ Patented recirculating ball bearing design. Available in lengths up to 118".

Aluminum Structural Extrusion System



☐ Perfect for quick assembly of slides, bases, test fixtures, tables, work surfaces.

Techno isel U.S.A. Division

2101 Jericho Turnpike, Box 5416,
New Hyde Park, NY 11042-5416
Phone: 516-328-3970 • Fax: 516-326-8827

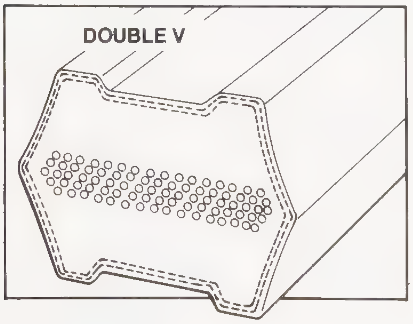
Circle 151

tured in special sections for dual drives.

Classical sections A through D are available in double (or hexagonal) configurations termed AA through DD, which operate from either side over standard V-belt sheaves. Drives may be single or multiple as with conventional belts.

Because of the increased thickness and mass of dual-drive belts, they have lower power ratings than the same sections in conventional belts. Dual-drive design also is more complex and requires an analysis of tensions and wrap angles at each shaft.

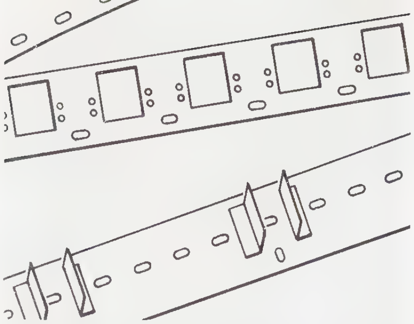
Synchronous belts of XL, L, and H sections are available in dual-drive sections, termed DXL, DL, and DH. Conventional synchronous belts can be used in dual drives if the flat side of the belt can be used as a working surface for shafts not requiring positive ratio relationships. Synchronous belts also can be manufactured with V-ribbed backs, with the V-ribs requiring less tension and providing more positive tracking than a flat surface.



Double-sided V-ribbed belts have been built on an experimental basis, but so far they have demonstrated little advantage over conventional V-ribbed belts with the backside drive provided by the standard flat surface. Dual drives based on conventional V-ribbed belts have already been applied successfully in agricultural machinery, home laundry equipment, and automotive accessory drives.

Metal belts

Metal belts once were primarily metal bands with the ends manually welded together. Riveted attachments provided some additional function but the belts were most often used in friction drives. Today, precise laser and electron-beam welding replace riveting and imprecise hand welds to produce strong connections in stainless steel, titanium, nickel and alloys. Special thicknesses range down to 0.002 in. Widths as narrow as 0.027 in. are commercially available. At the other size extreme, belts may be up to 0.030 in. thick and 30 in. wide. Total length ranges from 6 in. on the low end to many feet.



Precise laser and electron welding allows endless flat belts of stainless steel, titanium, nickel, and alloys. Units are available with smooth, precise butt welds and other weld configurations. Perforations allow sprocket drives or vacuum conveying, while attachments transport components or hold parts properly for assembly.

Advantages of metal belts come from their material, usually 300 series stainless steel. Some advantages to metal belts are:

- High strength-to-weight ratio. Thin belts of high tensile-strength alloys have low mass and inertia.
- Good dimensional stability. Because they are almost unstretchable, metal belts are accurate for timing or registration operations.
- Good corrosion resistance. Stainless-steel alloys are inert, nonabsorbent, easily cleaned, suitable in corrosive environments and in the sterile conveyance of pharmaceuticals.
- Resist high temperature. Metal belts may be used at elevated temperatures in baking and infrared oven-curing installations.
- Conduct heat and electricity. Alloys may be selected for applications requiring electrical conductance, heat transfer, or magnetic properties.

There are three areas of metal-belt applications: friction drives, timing or positioning belts, and drive tapes or metal belts with ends. Friction drives include plain metal belts, coated belts, and perforated belts. Timing and positioning belts are used in place of lead screws, gear trains, articulated arms, and other alternative devices that are usually more complicated, more expensive or less precise.

Metal chains

There are three methods of transmitting power mechanically from shaft to shaft: chain drives, gears, and flexible belts. The chief advantage of chains (and belts) over gears is that chains can be used with arbitrary shaft center distances. Also, compared to gears, chains are simpler and generally less costly.

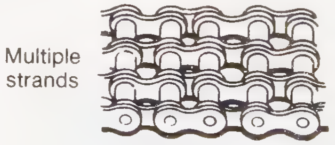
All drives can be engineered to provide a specific capacity and service life, but within specific size constraints, chains generally do not have capacities or service lives equal to those of gears. Compared to belts, chains offer advantages in capacity and service life at temperature extremes. Chains also provide positive drive ratios.

Chains are available in a range of accuracies extending from classifications of "precision" to "nonprecision." There is no firm boundary between the two, but nonprecision chains are those not providing extremely close fit between sprockets and link, nor are they designed to articulate with exceptional smoothness. In this class are detachable, pintle, and welded-steel chain. These types are low-cost chains intended primarily for low-speed drives below 50 hp.

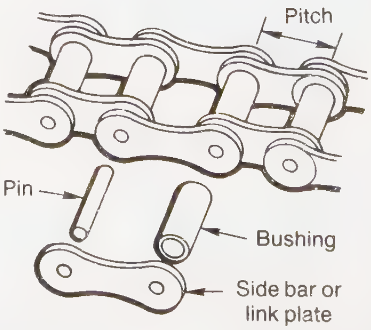
Precision chains are designed for smooth, free-running operation at high speeds and high power, ranging to over 1,000 hp. The most common precision chain is the roller chain.

Horsepower ratings for chains have been established by the American National Standards Institute (ANSI) and are based on criterion where the chain supposedly wears until it jumps the sprockets before failing from fracture. For a discussion of chain drives, see *Chain drives* in the Mechanical Fixed-Speed Drives section.

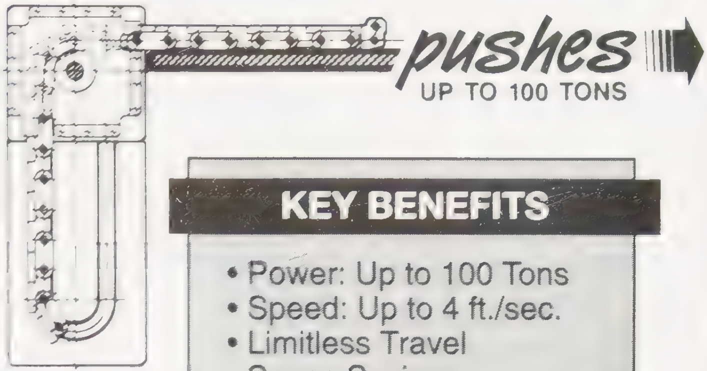
Roller chain: The basic type of power chain used throughout industry. Rated at up to about 500 hp for single-strand chain. Multistrand types are available at significantly higher horsepowers. (For example, ratings for four-strand chain exceed 2,000 hp.) Precision construction provides efficient, low-loss, quiet operation. Rated values



ROLLER



SERAPID RIGID CHAIN



Because of the unique design of the links, the SERAPID rigid chain can provide an answer to load movement problems over long distances, whether pulling or pushing, lifting or lowering, from a few kilogrammes to loads well in excess of 100 ton.

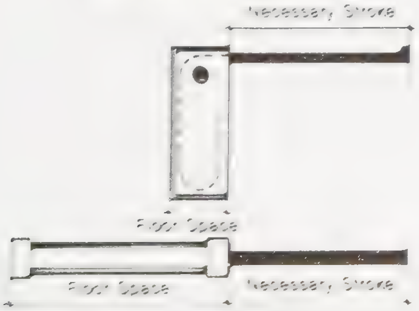
The system allows precise positioning on each stroke and offers space saving benefits compared with conventional systems.

In vertical load movement applications, the use of the SERAPID system can mean, in many instances, a reduction in the superstructure requirements, as the thrust reaction is absorbed on the ground.

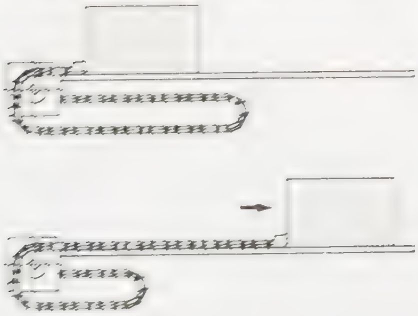
KEY BENEFITS

- Power: Up to 100 Tons
- Speed: Up to 4 ft./sec.
- Limitless Travel
- Space Savings
- Accurate Positioning
- Safety

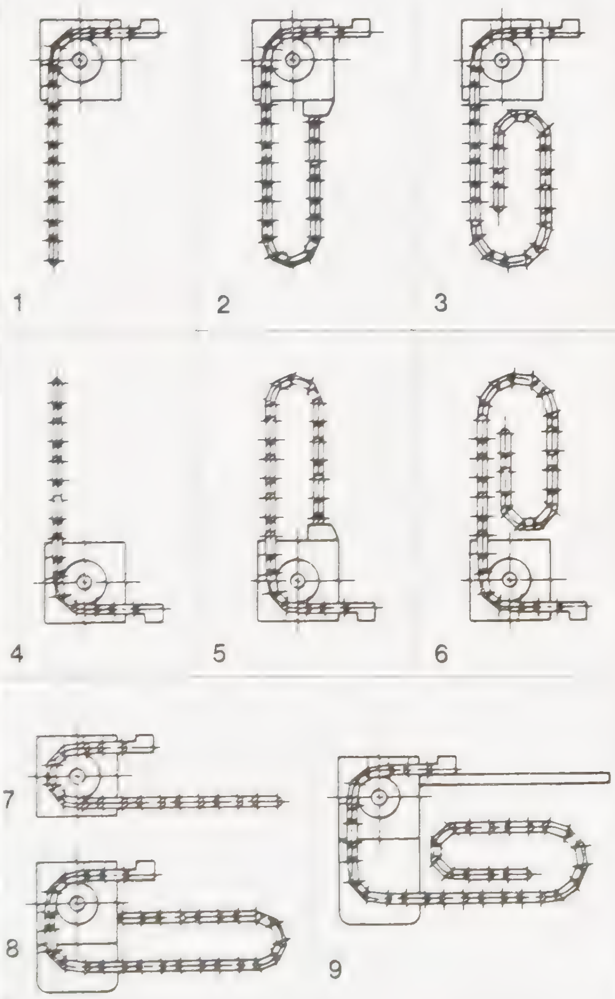
SPACE SAVINGS



MOVEMENT OF A LOAD



EXAMPLES OF CHAIN RETURN



TECH-ASSIST CORP. 1711 B Larchwood, Troy, Michigan, U.S.A. 48083
Tel: (313) 524-9417 FAX: (313) 524-9442

Circle 157

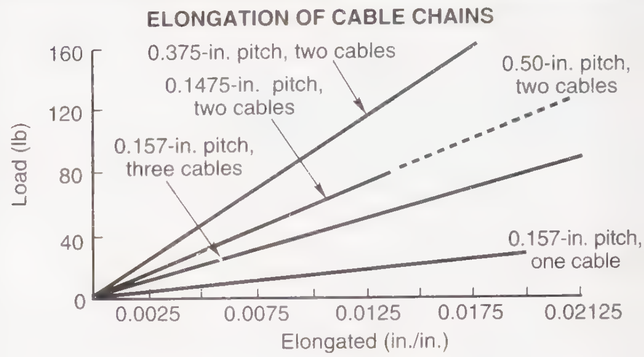
GUIDELINES FOR SELECTING PLASTIC CHAIN

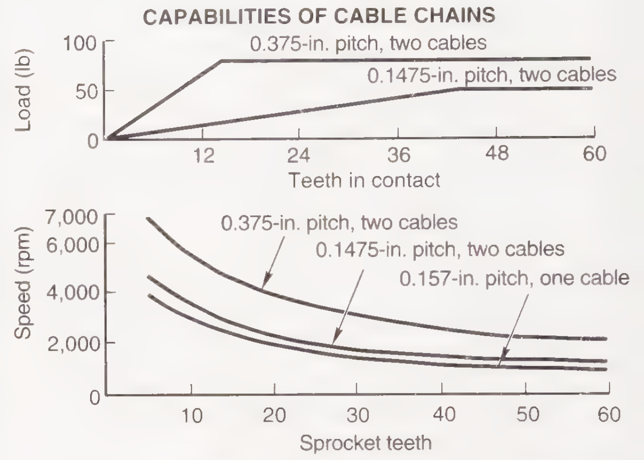
Because plastic chains are available in such a wide variety of materials and designs, there is no single sizing guideline. However, within the general chain groups, there are a few rules-of-thumb for selecting pitch and material. Then, experts suggest, to be certain of the selection, test a sample under actual operating conditions.

Cable chains should be sized to operate with no more than one-half their breaking strength and limited to about 1,8000 rpm on the small sprocket. Once a chain is selected, graphs for load, speed, and elongation help pinpoint maximum operating conditions. The graphs for some typical performance curves show how these factors change with sprockets size and the number of teeth the chain engages.

Rollerlike plastic chain in ½ to ¼-in. pitches should have working loads limited to about one-third of the chain's break strength. Then, some allowance must be made for material elongation. The table *Typical properties of plastic roller chain* indicates how much elongation to expect. A chain tensioner may be in order if elongation causes sprocket jumping. Tests show that about 90% recovery occurs within 30 min after load removal.

Although most plastic chain does not require lubrication, performance can occasionally be improved with it. For example, when the drive operates dry and continuously, manufacturers recommend an occasional light spray of silicone.





Rated working loads for large link chain

Speed to sprocked center-distance ratio (fpm/ft)	Pitch (in.) 1.63	2.3	2.6	3.1
0.1	800	1,100	1,350	2,000
0.2	750	1,050	1,200	2,000
0.5	700	950	1,050	2,000
1.0	600	800	950	1,850
2.0	500	680	850	1,500
5.0	400	540	750	1,130
10.0	330	450	650	920

Larger links or chain with pitches of 1.63 in. and greater, are generally selected with the help of a V/D ratio, where V = chain speed, fpm; and D = distance between sprocket centers, ft. Then refer to the table *Rated working loads for large link chain*, to select an initial chain size.

For example, a 700-lb load is moved by chain at 60 fpm. If the sprocket centers are 15 ft apart, what pitch chain should be considered first? The speed to distance ratio, $V/D = 60/15 = 4$. Therefore, from the chart, a 2.609-in. pitch chain appears to be the best selection.

Typical properties of plastic roller-like chain

	Nylon MoS_2 filled (Nylatron)			Acetal (Deirin)			Polypropylene			Polyvinylidene difluoride (Kynar)		
Water absorption in ⅛-in. thick sample, 24 h soak (%)	0.8			0.25			0.01			0.05		
Resistance to:												
Weak acids	Good			Good			Excellent			Excellent		
Strong acids	Poor			Fair			Attacked slowly by oxidizing acids			Excellent		
Weak alkalies	Excellent			Good			Excellent			Excellent		
Strong alkalies	Good			Good			Excellent			Excellent		
Organic solvent	Good for most			Good for most			Good below 80° C			Good for most		
Pitches (in.)	¼	⅜	½	¼	⅜	½	¼	⅜	½	¼	⅜	½
Tensile strength (lb)	65	136	173	63	136	175	29	66	89	56	109	141
Elongation at 75% tensile load (%)	14	9	7	5	5	3	6	5	4	7	5	4
Recovery of elongation 30 min after removing load (%)	87	91	88	98	95	95	95	94	92	92	94	95

Your Drive and Automation Component Source

Dedicated to the standardized production of over 80,000 drive and automation components so that you can spend your time designing - not hunting for parts.

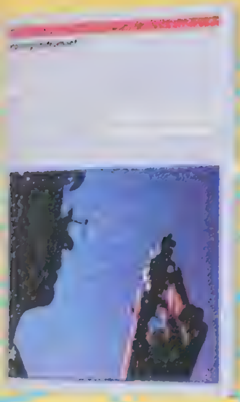
Stock Drive Products
Sterling Instrument
Divisions of DSG

PRECISION & COMMERCIAL
INCH & METRIC

• Bearings (Ball, Needle Roller, Non-Metallic, Sintered, Spherical, Thrust) • Belts (Timing, Double Sided, Flat, "V", Round Endless) • Bore Reducers • Bushings • Cables • Cams • Cam Followers • Chains (Ladder, Roller) • Clamps • Clutches • Collars • Couplings (Ball, Bellows, Flexible, Helical, Multi-Jawed, Offset, Oldham, Schmidt, Spring) • Dials • Differentials • Fasteners • Flexible Shafts • Flexirack • Friction Drive Wheels • Gears (Anti-Backlash, Bevel, Blanks, Clamp Type, Cluster, Helical, Internal, Miter, Spur, Worm) • Gearheads • Handles • Hex Stock • Idler Rollers • Idlers • Keys • Knobs • Ladder Chain • Limit Stops • Non-Circular Gears • Pawls • Pinions • Pinion Wire • Pins (Cotter, Dowel, Groove, Hitch, Roll, Spirol, Taper) • Pulley Flanges • Pulleys (Timing, "V", Flat Belt, Grooved, Idler) • Pulley Stock • Racks • Ratchets • Right Angle Drives • Shafts • Sheaves • Shims • Sleeves • Speed Reducers • Splines • Sprockets • Universal Joints • "V" Guide System • Washers (Belleville, Curved, Thrust, Wave)

Special Products: AC Motors • Axial Fans • DC Motors (Brushless, Pancake) • Gearheads • Gearmotors • Optical Encoders • Speed Reducers • Stepper Motors • Tachometers • Vibration Mounts • Rubber Mounts (Finger-Flex, Channel, Rectangular, Ring-Style, Iso Pads) • Base and Leveling Style Mounts (Spring Suspension, Elliptic Leaf Spring, Damped Spring, Leveling Base, Low Profile, Heavy Duty, Leveling Carry Mounts)

SDP Stock Drive Products
S Sterling Instrument
Divisions of DSG
2101 Jericho Turnpike • Box 5416
New Hyde Park, NY 11042-5416
Phone: (516) 328-3300
FAX: 516-326-8827



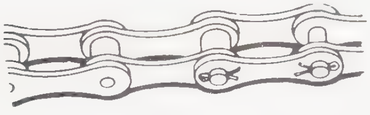
Circle 159

Circle 160

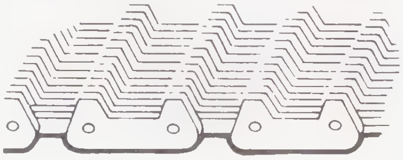
Circle 161

are predicated upon adequate lubrication covered by ANSI B29.1. In the smaller sizes (below ½-in. pitch; actually "bushing" chains) speeds can exceed 9,000 fpm. Self-lubricating types (stud-bushing chain) have oil-impregnated sleeve bearings. They are almost capable of running at the same loads as true roller chain, but at the lower end of the speed range. They provide a service life intermediate between nonlubricated and well-lubricated roller chain.

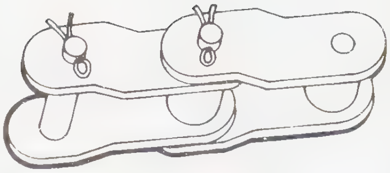
Double pitch: Designed for service less rigorous than that handled by standard roller chain. Provides the same precision construction and efficient operation of standard roller chain, except that pitch is twice as long (providing a lighter-weight construction) and ratings go only to 92½ hp. Functions well on drives with long center distances. Covered by ANSI B29.3.


DOUBLE PITCH

Inverted silent tooth: A more expensive type of chain that operates smoothly, quietly, and dependably in rigorous applications. Often used as a power takeoff from the prime mover in heavy equipment and in some automobiles. Also used as a timing chain (camshaft drive) in engines. Power capabilities generally equivalent to those of roller chain, except that silent chains reach maximum power at maximum rpm, whereas roller chains reach maximum power far below their maximum rpm.

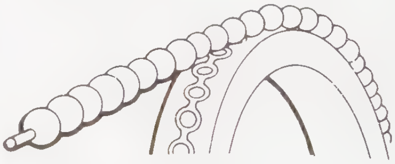

SILENT

Offset sidebar: The most costly of precision chains. More costly than detachable, pintle, or welded steel, but able to carry heavier loads (up to 425 hp) and able to run at speeds to 2,250 fpm. Because of its "open" construction, offset sidebar tends to be tolerant of dirt and debris that might cause binding in a roller chain. Offset sidebar is also more tolerant of misalignment or twisting of the sprocket axes. This type is rugged and durable and often is used to drive construction machinery. Serves well as conveyor chain in high-temperature ovens. Generally does not provide the speed or power capability available with roller chain. Well suited to use over cast sprockets at reduced speed. Larger sizes are covered by ANSI B29.10.

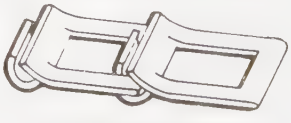

OFFSET SIDEBAR

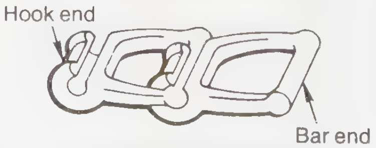
Bead chain: Light-duty types of chains generally used for manual-control systems such as those in television tuners and air-conditioner controls. They are also used in low-powered systems such as paper drives for business machines and laboratory recorders. Available in four standard bead diameters of 3⁄32, ⅛, 3⁄16, and ¼ in., rated at 15, 25, 40, and 75 lb.

Bead-belt chain, a variation of the basic type, consists of plastic beads molded onto a flexible cord. This type can run faster than all-metal chain but does not carry as much load.


BEAD

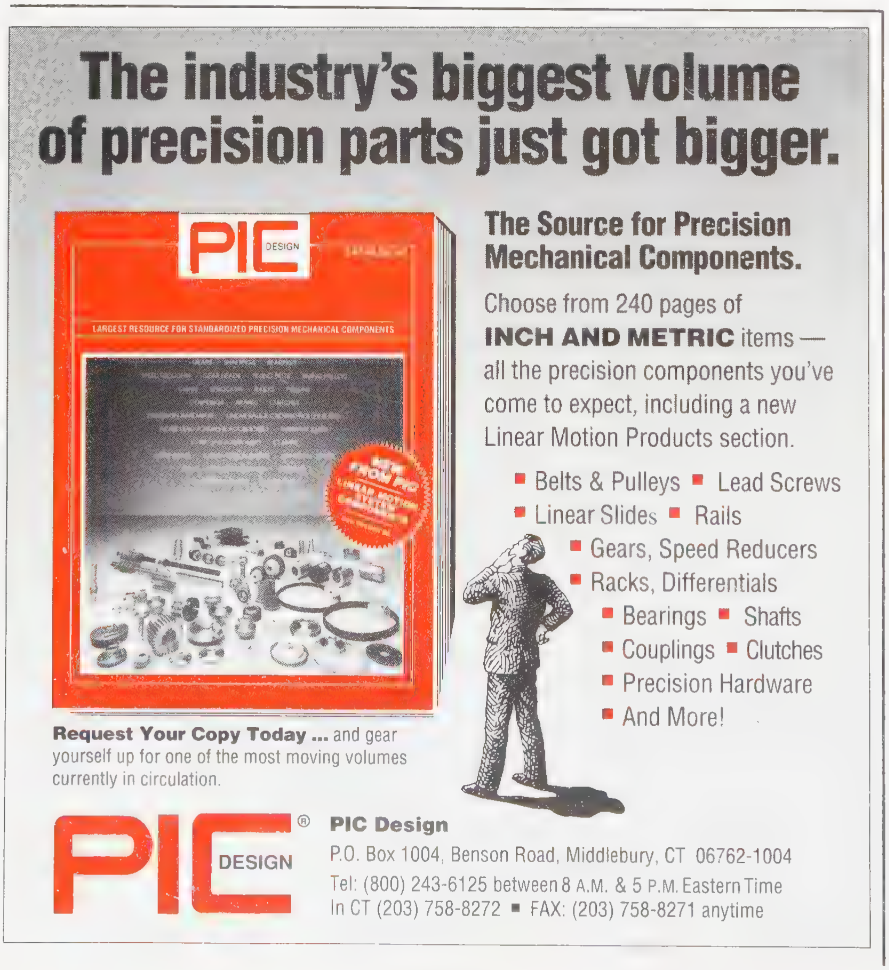
Detachable: The lightest, simplest, and least costly of all chains capable of transmitting significant power up to 25 hp at up to 350 fpm, but not as smooth running as precision chains. Does not require lubrication and, thus, is well suited to operation where lubricant might wash or bake away or where dust or granular materials would stick to a lubricated chain. Commonly used on farm machinery. Detachable chain in steel and in malleable iron are covered by ANSI B29.6 and B29.7.


DETACHABLE STEEL



DETACHABLE IRON

Pintle and welded steel: For slightly more rigorous service than de-


The industry's biggest volume of precision parts just got bigger.

The Source for Precision Mechanical Components.

Choose from 240 pages of **INCH AND METRIC** items — all the precision components you've come to expect, including a new Linear Motion Products section.

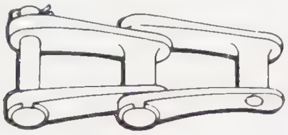
- Belts & Pulleys ▪ Lead Screws
- Linear Slides ▪ Rails
- Gears, Speed Reducers
- Racks, Differentials
- Bearings ▪ Shafts
- Couplings ▪ Clutches
- Precision Hardware
- And More!

Request Your Copy Today ... and gear yourself up for one of the most moving volumes currently in circulation.

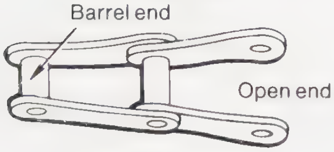
PIC DESIGN®
PIC Design
P.O. Box 1004, Benson Road, Middlebury, CT 06762-1004
Tel: (800) 243-6125 between 8 A.M. & 5 P.M. Eastern Time
In CT (203) 758-8272 ▪ FAX: (203) 758-8271 anytime

Circle 163

tachable chain. Applications are basically similar to those of detachable. Often designed to run on the same sprockets as detachable. Rated to operate at up to 40 hp and 450 fpm. Does not require lubrication. Not as smooth running, strong, or durable as precision



PINTLE

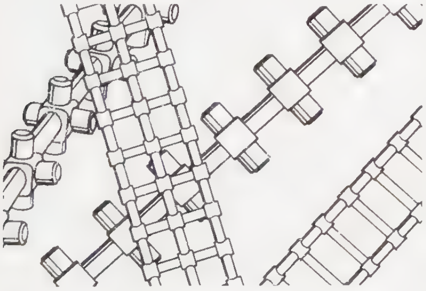


WELDED STEEL

chains. Welded steel chain generally can carry heavier loads and offers greater wear resistance than pintle.

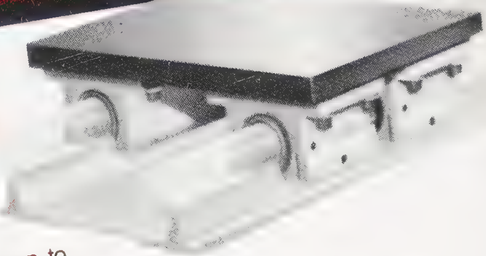
Plastic chain

The variety of plastic chain available includes traditional designs with discrete links that connect to form almost any length, and newer designs that include one, two, and three parallel strength members. The traditional chain form of separable links is available from 0.125 to 6-in. pitches, and newer styles from 0.098 to 0.5 in.



The advantages of chain over belts is that it can be assembled around obstacles, is readily connected to form almost any length, and has favorable load and life ratings. Typically, a 0.125-in. pitch chain of acetal resin has a break strength of 7 lb, a working load of 5 lb or less, and need not be replaced until elongation exceeds about 3%. Large pitch link chains typically use a steel pin to link units together. Models with 6-in. pitch typically have an average ultimate strength of 5,500 lb and an allowable working load of 1,500 lb.

New style chains, sometimes called cable drive chain, combine features of link chain and synchronous belts. Generally, these chains are molded plastic links on 7 × 7 stainless-steel wire-rope strength members. On single strength



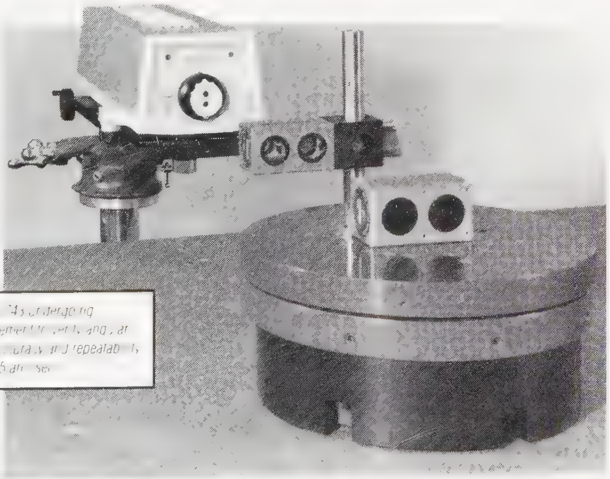
PERFORMANCE
PRODUCES
PROFITS

WITH LINTECH®
TWIN RAIL®
CARRIAGE
ASSEMBLIES

- Complete slide assemblies up to 16' in length with load ranges of 720 lbs. to 9400 lbs., are available.
- Seven standard shaft sizes are available from stock for immediate delivery.
- For more detailed information, please send for a free LinTech Products catalog.

LINTECH
1845 Enterprise Way, Monrovia, CA 91016-9913
In CA 800-843-8423 Outside CA 800-435-7494
TWX 910-321-7494 FAX 818-303-2035

Circle 164



When your definition of Quality
is measured in submicron accuracy...

Dover Instrument's Aerostatic Rotary and Multi-Axis Positioners
meet your most demanding requirements.

Dover Model [illegible] undergoing laser measurement [illegible] angular positioning accuracy and repeatability to less than .5 arc sec

Dover's Aerostatic Spindles, Slides, XY Stages, and Servo Controllers
are designed and manufactured under a Total Quality Management program
Send for Dover's new Precision Products Catalog

DOVER
DOVER INSTRUMENT CORPORATION
200 Flanders Road • P.O. Box 200
Westboro, MA 01581-0200
(508) 366-1456 • FAX (508) 366-9774

Circle 165

member chains, plastic links or drive pins are either dowels or cross shaped. Pitch-to-pitch accuracy is 0.0005 in. Pitches are as small as 0.1 in. on single strand designs while transmission power ranges to 7.5 hp on larger three-cable styles.

Cable chains are available in stocked circumferences and can be spliced on site. Typically, on-site splicing derates the chain load by about 50%.

Advantages of the cable chain are no play between teeth and cogs, operation with commercial spur gears, mountable on discs or inside rings to produce the effect of external or internal gear teeth, and no required lubrication.

Gear teeth

Tooth geometry is determined primarily by pitch, depth, and pressure angle.

Pitch: Standard pitches are usually whole numbers when measured as diametral pitch P, which is the ratio of the number of teeth to the pitch diameter in inches. Coarse-pitch gearing has teeth larger than 20 diametral pitch — usually 0.5 to 19.99. Fine-pitch gearing usually has teeth of diametral pitch 20 to 200.

Depth: Standardized in terms of pitch. Standard full-depth teeth have working depths of $2/P$. If the teeth have equal addenda (as in standard interchangeable gears), the addendum is $1/P$. Stub teeth have a working depth usually 20% less than full-depth teeth. Full-depth teeth have a larger contact ratio than stub teeth. Gears with small numbers of teeth may have an undercut so that they do not interfere with one another during engagement. Undercutting reduces active profile and weakens the tooth.

Mating gears with long and short addendum have larger load-carrying capacity than standard gears. The addendum of the smaller gear (pinion) is increased while that of the larger gear is decreased, leaving the whole depth the same. This form is known as recess-action gearing.

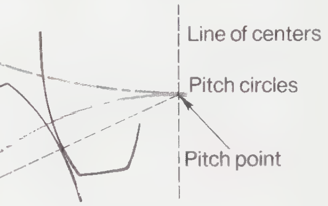
Pressure angle: Standard angles are 20 and 25°. Earlier standards included a 14¼° pressure angle that is still used. Pressure angle affects the force that tends to separate mating gears. High pressure angle decreases the contact ratio (ratio of the number of teeth in contact) but provides a tooth of higher capacity and allows gears to have fewer teeth without undercutting.

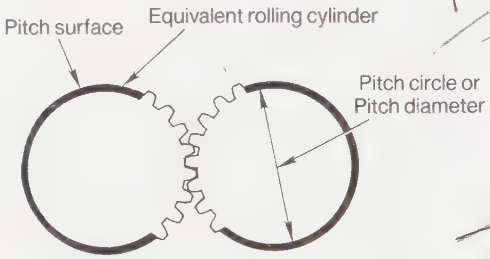
Backlash: Shortest distance between the noncontacting surfaces of the adjacent teeth.

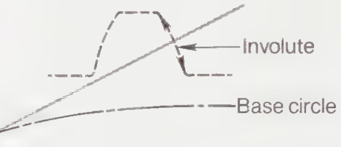
GEAR VOCABULARY

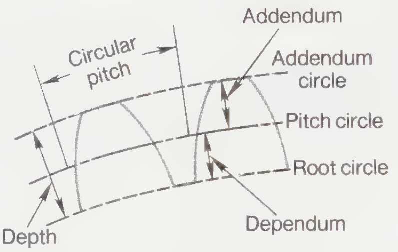
Because gear theory is complex, a brief explanation cannot convey all the important concepts and terms involved in the design and operation of gear sets. The illustrations provide a working vocabulary of gear terms. The examples used are for spur gears.

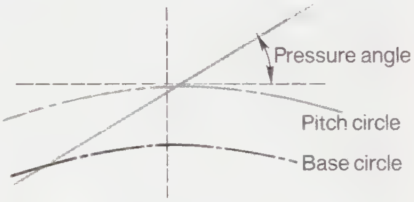
Gear size is normally defined in terms of **pitch circle** or **pitch diameter**. Two mating gears can be thought of as being equivalent to smooth cylinders in rolling contact, with their diameters being the pitch diameters. (For some gears, this analogy is not entirely valid.)











The **addendum** is the height of the gear tooth beyond the pitch circle, and the **dedendum** is the depth of the tooth below the pitch circle. The **circular pitch** is the spacing of gear teeth measured along the pitch circle. **Diametral pitch** is the ratio of the number of teeth to the pitch diameter in inches. **Gear depth** is the sum of addendum and dedendum (whole depth) or, since mating teeth do not project fully into the tooth space, the **working depth** (depth of engagement) is equal to the sum of the addendums.

The line connecting the centers of gear rotation is called the **line of centers**. The force transmitted from one tooth to another is directed along a line perpendicular to the tooth surface. Where that line intersects the line of centers is called the **pitch point**, which determines the radius of the pitch circle.

If a cord is wrapped around a cylinder, a point on the cord, as it is unwrapped from the cylinder, traces a curve called an **involute**, which is the basis of tooth geometry. The curve from which the involute is generated is called the **base circle**. An involute gear form provides constant angular velocity ratios between mating teeth.

Consider a line tangent to the pitch circle. A line through that point of tangency and tangent to the base circle forms an angle called the **pressure angle**.

NONCIRCULAR GEARS

Noncircular gears are basically cams or linkages in gear form; that is, a constant velocity or uniform input produces a nonuniform output. They can generate practically any continuous mathematical function not having a reverse slope.

The drive is positive, precise, and efficient, and capable of providing many choices of acceleration, velocity, and displacement patterns usually associated with cams.

Gears are commonly specified according to AGMA Class Number, which is a code denoting important quality characteristics. Quality numbers denote tooth-elements tolerances. The higher the number, the closer the tolerance. Gears are heat treated by case hardening, nitriding, precipitation hardening, or through hardening. In general, harder gears are stronger and last longer than soft ones. Thus, hardening is a device that cuts the weight

PLASTIC GEARS

Although many plastic gear design techniques are derived from metal-gear technology, plastic gears demand special consideration. In fact, plastic-gear design often requires attention to details that have no effect on metal gears, such as heat buildup from hysteresis.

The basic difference in design philosophy between metal and plastic gears is that metal-gear design is based on the strength of a single tooth, whereas plastic-gear design recognizes load sharing among gear teeth. In other words, plastic-gear teeth deflect more under load and spread the load over a larger number of teeth. In most applications, this load sharing increases the load-bearing capacity of plastic gears. And, as a result, the allowable stress for a specified number of cycles to failure increases as tooth size decreases to a pitch of about 48. Little increase is seen above a 48 pitch because of size effects and other considerations.

In general, the following step-by-step procedure will produce a good gear design when working with thermoplastic materials:

1. Determine the boundary conditions of the application; for instance, temperature, load, velocity, space, and environment.

2. Examine the short-term material properties to determine of the initial performance levels are adequate for the application.

3. Review long-term property retention in the specified environment to determine if the performance levels will be maintained for the life of the part.

4. Using the physical property data, calculate the stress levels caused by the various loads and speeds.

5. Compare the calculated values with allowable stress levels and redesign if necessary to provide an adequate safety factor.

Plastic gears fail for many of the same reasons as metal gears, including wear, scoring, plastic flow, pitting, fracture, and fatigue. The causes of these failures also are essentially the same.

The teeth of a loaded rotating gear are subject to stresses at the root of the tooth and at the contact surface. If the gear is lubricated, the bending stress is the most important parameter. Nonlubricated gears, on the other hand, may wear out before a tooth fails; therefore, contact stress is the prime factor in the design of these gears. Plastic gears usually have a full fillet radius at the tooth root. Thus, they are not as prone to stress concentrations as metal gears.

Bending stress data for engineering thermoplastics is based on fatigue tests run at specific pitch-line velocities. Therefore, a velocity factor should be used if the operating pitch-line velocity exceeds the test speed. Continuous lubrication can increase the allowable bending stress by a factor of at least 1.5. As with bending stress, the calculation of surface contact stress requires a number of correction factors. For example, a velocity factor is used when the pitch-line velocity exceeds the test velocity. In addition, a factor is used to account for changes in operating temperature, gear materials, and pressure angle. Stall torque is another important factor in the design of thermoplastic gears. Often, gears are subjected to a stall torque that is considerably higher than the normal loading torque.

If run at high speeds, plastic gears also are vulnerable to hysteresis heating which may be so severe that the gears actually melt. Such failures can be avoided by designing the gear drive so that there is a favorable thermal balance between the heat generated and that removed by inherent cooling processes.

There are two ways to cope with hysteresis heating. Either the rate of heat generation must be reduced or the rate of heat transfer must be increased. In either case, or by a combination of both, the gear temperature can be stabilized. If it does stabilize, the gear will run indefinitely until stopped by genuine fatigue failure. In such cases, the durability of plastic gears makes them quite attractive. For example, the high fatigue endurance of unfilled engineering resins usually gives them a fatigue life an order of magnitude higher than that of metal gears.

Hysteresis heating can be reduced by several methods. The preferred way is to reduce the peak stress by increasing the tooth root area available for the required torque transmission. Another way is to reduce stress on the teeth by increasing gear diameter. Peak stress also can be reduced by other manipulations described by classical theory.

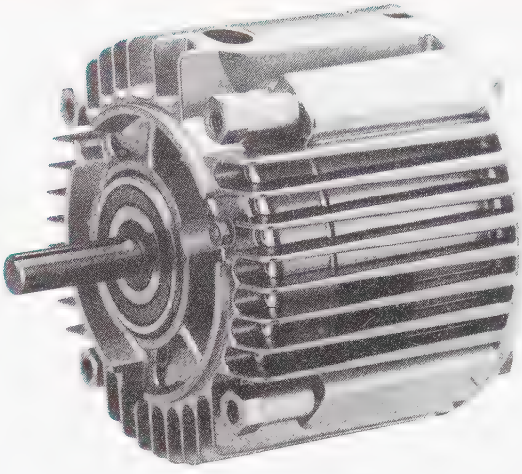
The use of stiffer materials — in short, using a material exhibiting less hysteresis — is another way to improve the life of plastic gears. There are several ways that a specific material can be made stiffer. For example, the crystallinity level of crystalline plastics such as nylon and acetal can be increased by appropriate processing techniques that can improve stiffness by 25 to 50%.

The most effective method to improve stiffness is through the use of fillers, especially glass fiber. Additions of glass fiber can increase stiffness by as much as 50 to 10 times, but this approach has a drawback. As previously mentioned, unfilled engineering resins have a fatigue endurance about an order of magnitude greater than that of metals. The addition of glass and other fillers significantly reduces this advantage, with the least improvement at the highest filler loadings. Therefore, the use of fillers to avoid hysteresis failure must take into account the trade-off between fatigue life and minimum heat buildup.

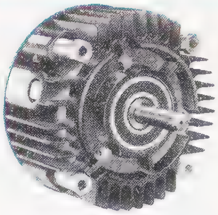
Fillers, however, also provide other improvements in the ability to resist hysteresis failure. Fillers such as glass fiber increase the heat conductivity of the gear. This helps remove heat from the peak stress region at the base of the gear teeth and also helps dissipate the heat. This heat removal is the other general factor that can be controlled to improve resistance to hysteresis failure.

The surrounding fluid, whether air or liquid, also has a substantial effect on cooling rates. If a fluid such as an oil bath is substituted for air, the heat transfer from the gear to the oil is usually about ten times that for transfer to air. The degree of agitation of the air or oil also affects heat transfer by a like amount or more. In addition, heat transfer is increased if the cooling medium is cooled by a heat exchanger or by system design having a similar effect.

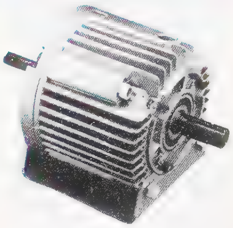
DODGE CLUTCH-BRAKE MODULES



C-Face Clutch/Brake
or Clutch Only



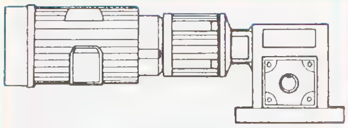
C-Face Brake Only



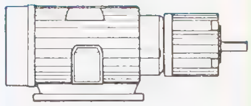
Base Mounted Clutch/Brake
or Clutch Only

DODGE Clutch/Brake Modules allow the motor to run continuously while the driven load is started and stopped. Modules are shipped completely assembled, adjusted and burnished from the factory and are ready for full torque operation. DODGE modules are designed to match NEMA ratings and C-face mounting dimensions for simple installation. Modules provide motion control in processes that: accumulate, sort, stage, fill, test, weigh, label, pack seal, band, strap, wrap, inspect, palletize, store, retrieve, etc. and other unit handling applications where repetitive starts and stops are needed.

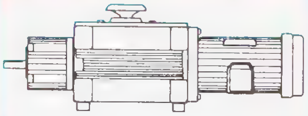
TYPICAL APPLICATIONS:



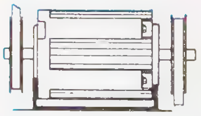
C-Face Mounted Clutch/Brake
Module and DODGE TIGEAR®
Right Angle Reducer



C-Face Mounted
Clutch/Brake Module



Clutch/Brake Module
Mounted on DISCTRAC™
Variable Speed Drive



Foot Mounted Electric
Clutch/Brake Module

TECHNICAL DATA:

IMC/IMS MODULES	STATIC TORQUE (Lb.-Ft.)	MAX. HP @ 1800 RPM	MOTOR FRAME	SHAFT DIA. (In.)	CYCLE RATE RANGE ★ (CPM)
50	22	1	56C	⅝"	5-80
100	34	2	56C	⅝"	5-75
180	34	2	143/145TC	⅞"	5-75
210	100	7½	182/184TC	1⅛"	5-80
256	100	10	213/215TC	1⅜"	5-80

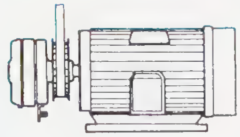
★ Actual allowable cycle rates vary with load. Consult selection charts in catalog.

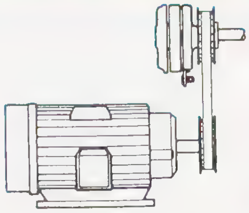
FEATURES/BENEFITS:

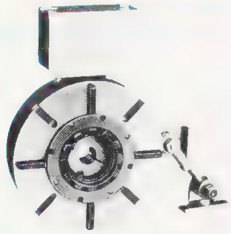
- Assembled, adjusted, burnished — factory tested to provide lowest installed cost. Saves approximately 30 minutes during installation and 1 to 24 hours (depending on load) at start-up. Burnishing can be a lengthy process, especially for lightly loaded applications.
- Higher torque ratings on DODGE units may allow faster cycle rates, less slip, improved positioning accuracy
- DODGE modules operate cooler (have improved thermal capacity) — improves torque control (less torque fade due to heat), yields longer life.
- Larger bearings for longer life and greater O.H.L. capacity.
- System Assembly — motor/module/reducer. DODGE can assemble and pre-run assembly.

DODGE® SHAFT CLUTCHES & BRAKES

IEC Shaft Clutch


Clutch (or Brake) on Motor


Clutch (or Brake) on Shaft


IEB Shaft Brake

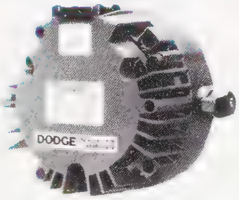
IEC CLUTCH/ IEB BRAKE	STATIC TORQUE (Lb.-Ft.)	CLUTCH MAX. HP @ 1800 RPM	BRAKE MAX HP @ 1800 RPM	CLUTCH BORE RANGE (In.)	BRAKE ■ BORE RANGE (In.)	CYCLE RATE RANGE ★ (CPM)
375	22	1	2	1/2"-5/8"	1/2"-5/8"	5-80
475	34	2	3	5/8"-7/8"	Up to 1"	5-75
650	100	3	7 1/2	1"-1 3/8"	Up to 1 7/16"	5-80
825	175	7 1/2	20	1"-1 3/8"	Up to 1 11/16"	5-80

■ Sizes 475 and larger utilize TAPER-LOCK® Bushings.
★ Actual allowable cycle rates vary with load. Consult selection charts in catalog.

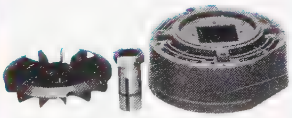
EATURES/BENEFITS:

- Assembled, adjusted, burnished — factory tested to provide lowest installed cost.
- Higher torque ratings on DODGE units may allow faster cycle rates, less slip, improved positioning accuracy.
- Armatures and clutch rotors are easily replaced on 650 sizes and larger without removing unit from shaft.
- Heavy duty spline drive reduces component wear, longer life.
- Soft-mount on clutch reduces engagement noise, quieter operation.

DODGE® MOTOR BRAKES



C-Face (Fan Mounted) Motor Brake


Adapter Kit for TEFC (Reliance) Motors

Double C-Face Motor Brake

EATURES/BENEFITS:

- Assembled, adjusted, burnished — factory tested, yields lowest installed cost.
- Manually adjusted or self adjusting models available.
- DC brake is quieter (no AC hum).
- Can be vertically or horizontally mounted without adjustment or additional parts.
- Runs cooler, allows longer life, less torque fade.

UNIT SIZE	STATIC TORQUE (Lb.-Ft.)	MOTOR FRAME	MAX. HP @ 1800 RPM ■	CYCLE RATE RANGE † (CPM)
IMB/S-3	3	56C 143/145TC 182/184TC★	1	1-10
IMB/S-6	6	56C 143/145TC 182/184TC★	2	1-10
IMB/S-10	10	56C 143/145TC 182/184TC★	3	1-12
IMB/S-15	15	143/145TC 182/184TC★	5	1-12
IMB/S-20	20	143/145TC 182/184TC★	5	1-12
IMB/S-25	25	143/145TC 182/184TC★	5	1-12

★ Reliance 182/184TC frame motors prepared for a brake have 140 C-face dimensions.
■ Based on 1.0 Service Factor.
† Actual allowable cycle rates vary with load. Consult Selection Charts in Catalog.

Specify DODGE Clutch/Brakes.
Move faster with the leader.™

ODGE / P.O. Box 499 / 2 Ponders Court / Greenville, S.C. 29602-0499 / 803-297-4800 / FAX: 803-281-2318

© Reliance Electric Company, 1990

Circle 166

RELIANCE ELECTRIC

and size of gears. Some processes, such as flame hardening, improve service life but do not necessarily improve strength.

Design checklist

The larger gear in a pair is called the gear; the smaller is called the pinion.

Gear ratio: The number of teeth in the gear divided by the number of teeth in the pinion. Also, ratio of the speed of the pinion to the speed of the gear. In reduction gears, the ratio of input to output speeds.

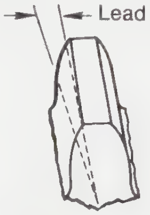
Gear efficiency: Ratio of output power to input power. (Includes consideration of power losses in the gears, in bearings, and from windage and churning of lubricant.)

Speed: In a given gear, normally limited to some specific pitchline velocity. Speed capabilities can be increased by improving accuracy of the gear teeth and by improving balance of the rotating parts.

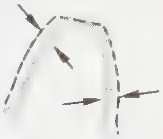
Power: Load and speed capacity is determined by gear dimensions and by type of gear. Helical and helical-type gears have the greatest capacity (to approximately 30,000 hp). Spiral bevel gears are normally limited to 5,000 hp, and worm gears are usually limited to about 750 hp.

GEARING TOLERANCES

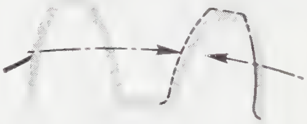
Lead tolerance: The difference between measured and specified axial advance along the face on one tooth (as in a helical gear) or in one revolution of a worm.

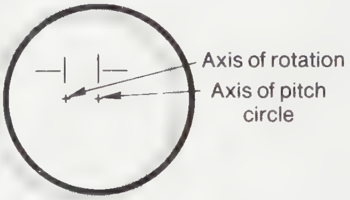


Profile tolerance: Deviation of the profile of tooth form from the theoretically correct profile, with measurement made in the plane of rotation. Tip relief and any portion of the tooth surface below the active profile are not considered. Applicable to quality numbers 8 and higher.



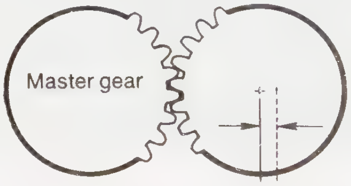
Pitch tolerance: Variation in distance between corresponding points of adjacent teeth. Measurement preferably made at or near pitch circle. Applies to gear quality numbers 6 and higher.





Runout tolerance: Variation between axis of the pitch circle and axis about which the gear rotates. It is twice the eccentricity and includes the effect of side runout or wobble. Applies to all gear quality numbers.

Total composite tolerance: Variation in center distance when a gear is rotated one revolution in tight mesh with a master gear. Includes effects of all tooth and runout variations. Applies to gear quality numbers 8 to 12. Tooth-to-tooth composite tolerances apply to center distance variation in tooth-to-tooth movement.



Special gear requirements

Backlash: The AGMA standards recommended backlash ranges to provide proper running clearances for mating gears. An overly tight mesh may produce too much noise, overheating, and structural overload. However, some applications require zero backlash.

Quiet gears: To make gears as quiet as possible, specify the finest pitch allowable for load conditions. (In some instances, however, pitch is coarsened to change mesh frequency to produce a more pleasant, lower-pitch sound.) Use a low pressure angle. Use a modified profile to include root and tip relief. Allow enough backlash. Use high-quality numbers. Specify a surface finish of 20 μin. or better. Balance the gear set. Use a nonintegral ratio so that the same teeth do not repeatedly engage if both gear and pinion are hardened steel. (If the gear is made of a softer material, an integral ratio allows the gear to cold work and conform to the pinion, thereby promoting quiet operation.) Make sure critical speeds are at least 20% apart from operating speeds or speed multiples and from frequency of tooth mesh.

Tooth spacing: Some gears require high accuracy in the circular spacing of teeth. Thus, specification of pitch may be required in addition to an accuracy class specification.

Matched-set gearing: In applications requiring extremely high accuracy, it may be necessary to match pinion and gear profiles and leads so that mismatch does not exceed the tolerance on profile and lead for the intended application. For a more complete discussion of single-speed gear drives, read *Gearboxes* in the Mechanical Fixed-Speed Drives section. For multiple-speed transmissions, read the Mechanical Adjustable-Speed Drives section.

Brakes

Brakes are basically a clutch with one member held stationary. The objective with both classes of hardware is to take two shafts rotating independently at different speeds and bring them into partial or total engagement.

Connecting shafts can be by direct mechanical lockup, by mechanical friction, by electromagnetic action, or by hydraulic forces. Among the electromagnetic types, actual engagement may be mechanical, with electrical components used only for actuation.

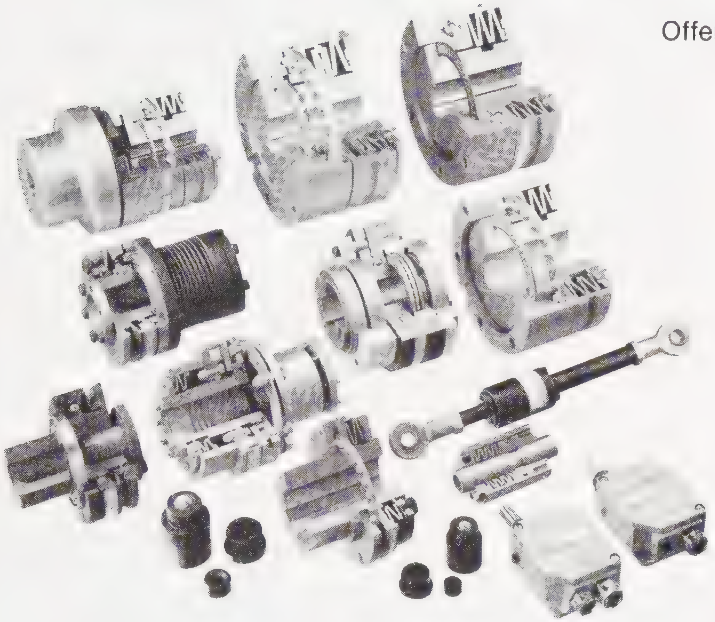
Mechanical clutches generally are the simplest and are normally used where an operator can actuate the clutch manually. Vehicles, for example, typically use mechanical clutches. Electric clutches are generally used where remote actuation is required (as on automatic machinery) or where special slip characteristics are required.

Hydraulic or fluid couplings are used in place of mechanical clutches where exceptionally smooth engagement is required or where it is desired to have the clutch automatically pick up a load with an increase in input speed. They are also used where constant engagement and disengagement would result in too much wear and maintenance.

Clutches

Clutches rely on mechanical or electromagnetic action for torque transmission. However, they are usually identified by their mode of actuation: mechanical, electrical, pneumatic, or hydraulic.

mayr POWER TRANSMISSION PRODUCTS KEEP YOUR EQUIPMENT RUNNING



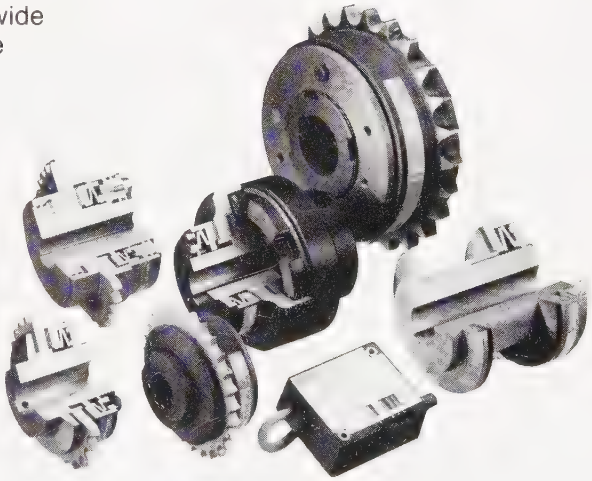
Offering the widest variety of mechanical torque limiting clutches on the market today, plus both disk type and bellows type flexible all steel couplings, and several specialized power transmission components, ***mayr*** has the products to keep your equipment running.

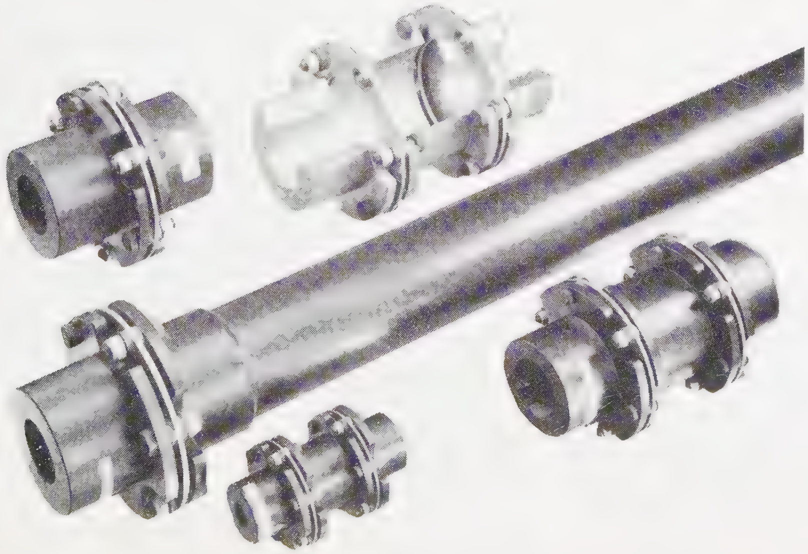
Our ball/detent torque limiting clutches prevent the costly damage and eliminate the unnecessary machinery downtime caused by overloads. Available in single and multiple position, free wheeling and torque sensing models, these versatile units feature either automatic or manual re-engagement, torque capacities from 0.37 to 140,000 ft.-lbs. and bores from 3/8 to 12 inches.

Our friction type torque limiters can be used with a wide variety of drive elements, such as single and multiple chain sprockets, V-belt pulleys, timing belt pulleys, gears, etc., and offer torque capacities from 1.5 to 37,000 ft.-lbs. and bore sizes from 3/8 to 7 inches.

Our disk type and bellows type torsionally rigid, all steel flexible couplings have torque capacities up to 44,000 ft.-lbs. and bore sizes from 3/8 to 10 inches. Featuring unitized disk packs and standard or special length spacer sleeves, these maintenance free couplings accommodate axial, angular and radial shaft misalignments.

In addition, ***mayr*** also offers a complete line of frictional shaft/hub locking devices.





For more information on any of our products please contact:

mayr
power transmission

Mayr Corporation
4 North Street
Waldwick, NJ 07463
Phone (201) 445-7210
Fax (201) 445-8019

Circle 167

Although the four operating modes are commonly considered to be highly competitive, each mode actually is restricted to a fairly well-defined area of application. Within each area, one method provides definite advantages in terms of cost, response time, and torque transmission.

Mechanical actuation is the simplest mode, and mechanically actuated clutches generally are the least expensive. Mechanical clutches can be actuated through hand or foot-operated linkages or cables, which provide a "feel" for the amount of engagement.

Small mechanical clutches are actuated directly with cams or levers, while larger clutches are operated through compound linkages. Usually, mechanical actuation is feasible only when the lever or pedal can be located near the clutch. Some clutches can be actuated from long distances, but friction losses in the linkage or cable may be high.

Because mechanical actuation depends on hand or foot operation, actuation forces are limited to about 75 lb. This relatively low clamping force limits its torque transmission to about 25,000 lb-ft and power transmission to about 2,500 hp (low compared to the tens of thousands of horsepower transferred by many machines). As a result, mechanically actuated clutches are restricted to vehicles and small industrial equipment such as hoists and cranes.

The major advantage of mechanical actuation (besides low cost) is the "touch control" the operator has over clutch engagement; he can closely control how quickly the output shaft comes up to speed.

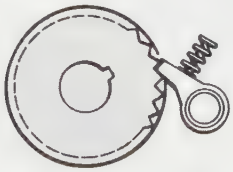
The biggest disadvantage to mechanical actuation is the need for an operator. Hand operation not only limits its clamping force and torque, it also limits response and cycling times. Normally, mechanically actuated clutches cannot be cycled more than a few times per minute without wearing the clutch elements or fatiguing the operator.

High temperature and contaminated atmospheres also are deterrents to using mechanical actuation. High temperatures increase clutch slippage, accelerating wear. Dirt can foul linkages (increasing required actuating force) and wear clutch elements. In some cases, using special housings and submerging the friction elements in an oil bath offsets the ill effects of contaminated atmospheres.

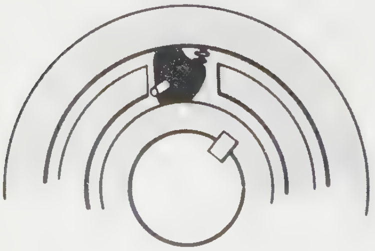
Pneumatic actuation is frequently encountered in industrial equipment. Air-actuated clutches transmit as much as 50,000 hp on machines such as

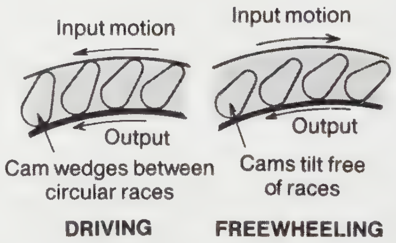
DEVICES FOR CONTROLLING MOTION DIRECTION AND OVERLOAD

Ratchet: A pawl, held by spring compression against gear teeth, permits rotation in only one direction. Depending on ratchet configuration, forward, reverse, free-running neutral, or locked positions are possible.

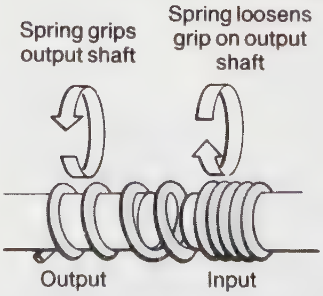


Cam: A spring-loaded cam is positioned between inner and outer races. The center of gravity of the cam is outside the radial point of contact, so the cam lifts off the inner race at high rotational speeds, preventing wear or heat generation. In other respects, the operation of the clutch is similar to that of a sprag clutch.



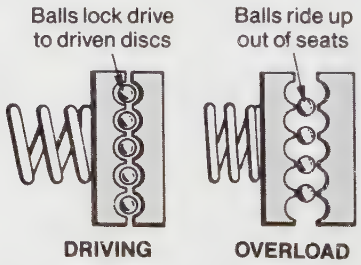


Sprag: Cams or sprags are mounted between two circular races so that rotation of drive race in the proper direction wedges the sprags between the two races. Reverse rotation rocks the sprags out of engagement. They operate at high speed and have zero backlash.

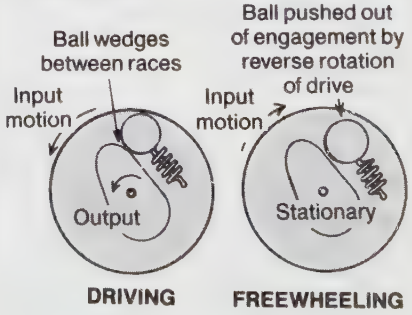

Spring grips output shaft
Spring loosens grip on output shaft
Output
Input

Wrapped spring: Input shaft is connected to output by a coiled spring. Rotation in one direction tightens spring and transmits torque. Reverse rotation loosens spring.

Overload clutches: These torque limiters automatically slip or disengage at a predetermined torque. Most types then reengage the load when torque drops to an acceptable level. They are used to prevent service overloads or to slip so that the input drive can overcome high starting inertias. They utilize a variety of clutching and release principles. The ball-detent clutch illustrated is a simple type suitable for light service.



Roller: Spring holds balls in contact with circular race and ramp so that rotation of race in the proper direction wedges the balls between race and ramp. Reverse rotation releases balls.


Ball wedges between races
Ball pushed out of engagement by reverse rotation of drive
Input motion
Input motion
Output
Stationary
DRIVING
FREEWHEELING

PUT THE BRAKES ~~ON~~ OFF

OGURA CLUTCH

- Ball Screws
- Servo Motors
- Robotics
- Medical Equipment

OGURA SPRING APPLIED BRAKES WORK WHEN YOU TURN THE POWER OFF

- Spring applied brakes for holding or stopping
- Wide standard torque and size range (1.75 in/lbs at a 1.5" diameter-880 in/lbs at a 13" diameter).
- Special Designs (Manual release, zero backlash, adjustable torque) available
- Inch and metric bores

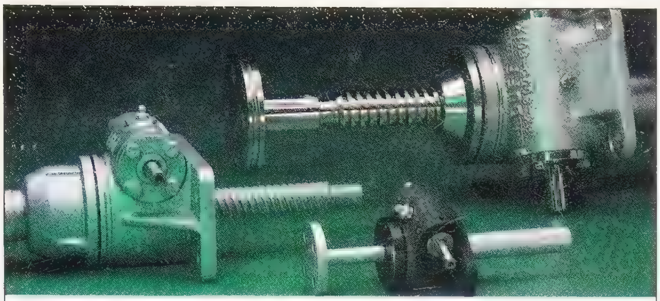
Ogura has one of the largest electromagnetic product lines in the world. For more information on this or any other clutch/brake product, please call or write:

OGURA CLUTCH/BRAKE

Kanematsu USA, Inc.
400 Cottontail Lane
Somerset, NJ 08873

Phone (908) 271-7359
Fax (908) 271-7357
WU Telex 130707

Circle 168



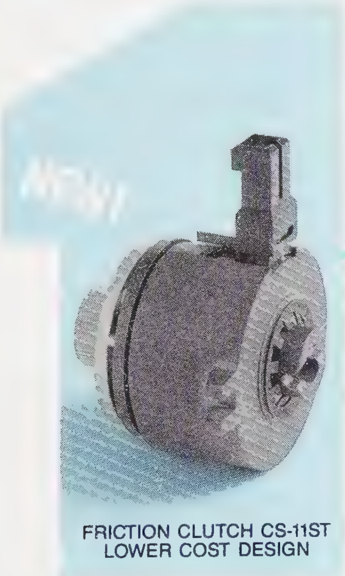
Easy Rider

With Duff-Norton's machine screw or ball screw actuators in tandem, uneven loads—up to 250 tons per actuator—ride easy. Uniform lifting speeds and precise positioning (in thousandths of an inch) make it handle smoothly. More than 200 standard combinations of mechanical actuators for manual or motorized applications. Available with raises to 20'.

Get our free catalog and design guide. Call or write Duff-Norton, P.O. Box 7010, Charlotte, NC 28241, (800) 477-5002, FAX (704) 588-1994.

Duff-Norton
Mechanical Actuators

Circle 169



FRICTION CLUTCH CS-11ST
LOWER COST DESIGN

ONLY ONE

You're looking at just one of a wide variety of highly engineered electromagnetic clutches and brakes for rotary motion control available to you from Deltran.

You are most likely to find exactly what you need at Deltran. Plus, we can custom-engineer a solution specifically for your application.

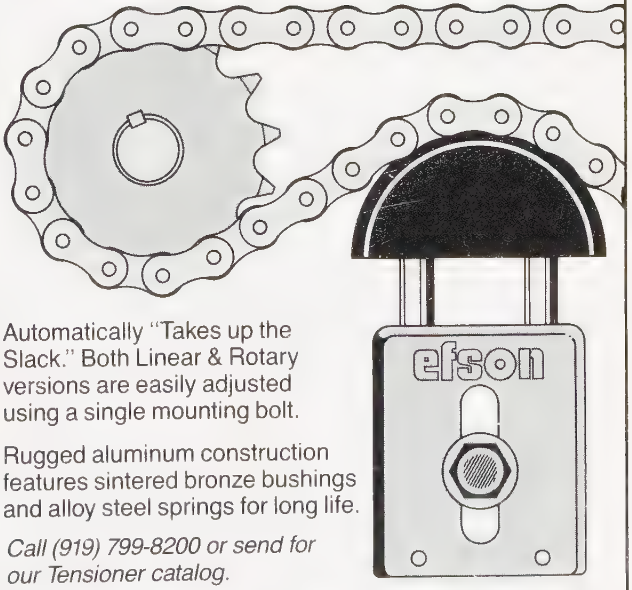
Xerox has awarded Deltran their Supplier Achievement Award four years in a row and "Just in Time" award three years in a row. There's a good reason why. . . world class quality. Call (716) 631-9800 or Fax (716) 631-9368 for more information and a copy of our catalog.

AMERICAN PRECISION INDUSTRIES
DELTRAN DIVISION

4401 GENESEE STREET • BUFFALO, NY 14225

Circle 170

HIGH-TECH TENSIONER



Automatically "Takes up the Slack." Both Linear & Rotary versions are easily adjusted using a single mounting bolt.

Rugged aluminum construction features sintered bronze bushings and alloy steel springs for long life.

Call (919) 799-8200 or send for our Tensioner catalog.

efson

2635 N. Chase Pkwy., S.E.
Wilmington, NC 28405
Phone (919) 799-8200
Fax (919) 799-9545

Circle 171

rolling mills, grinding mills, and coilers. Air actuation also is common on vehicles that are large enough to accommodate an air compressor.

The reason for the wide range of uses is the general availability of pressurized air. Almost every factory has compressed air available that is easily piped to the clutch. In addition, air is a comparatively safe medium with which to work.

Generally, air-actuated clutches are mechanical friction clutches modified to be engaged by air pressure and disengaged by spring action. Shop air, usually 80 psi, is used as the actuation source, and cycle rates to 80 times per minute are possible. Engagement usually is controlled through pistons and pressure plates. However, some air-actuated clutches use inflatable tubes or glands.

Air-actuated clutches transmit higher torques than equivalently sized mechanical or electric clutches. However, they fall short of the torques possible with hydraulic clutches.

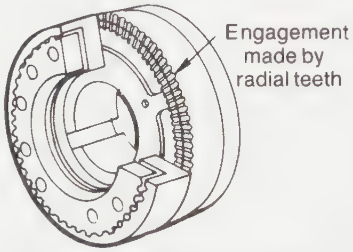
Perhaps the greatest asset of air-actuated clutches is their thermal capacity. Unlike electricity, air does not generate heat during extended periods of clutch engagement. What's more, air can be directed across the faces of the clutch plates to cool them.

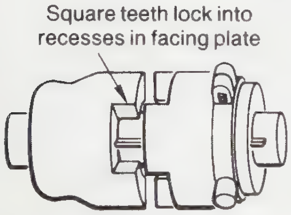
Air-actuated clutches can be used in almost any operating environment because the seals that prevent air leakage also keep out dirt. And actuation over long distances usually does not significantly lower air pressure at the clutch. Also, because static pressure maintains a constant force after the piston chamber is filled, power requirements for sustained torque transmission are almost negligible.

Air actuation generally is immediate, but in some cases it does provide some of the "touch control" of mechanically

MECHANICAL CLUTCHES

Tooth: Further refinement of the locking-tooth principle. Engagement is between a large number of small gearlike teeth or serrations. Running engagement is possible at up to 300 rpm. Generally available in capacities up to 300 hp per 100 rpm.



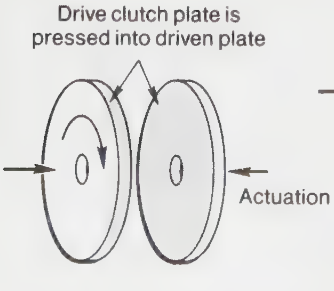


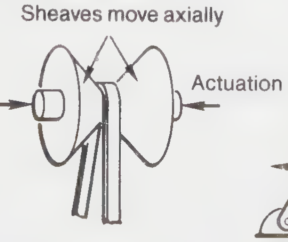
Spiral jaw: Eliminates some of the objectionable features of square-jaw type. Engaging surfaces are sloped to provide smoother running engagement. Can be engaged at speeds up to about 150 rpm. Available in same sizes and capacity ranges as the square jaw. Runs in one direction only and has a tendency to freewheel.

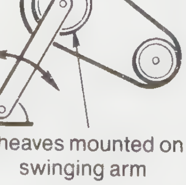
Axial: More complex and more expensive than drum type but offers a large friction surface and a higher capacity for a given size. The friction surfaces may be flat (disc type) or conical (cone type). Standard clutches are rated up to about 30 hp at 100 rpm. The clutches used in automobiles and most vehicles are specially designed axial types.

Multiple-disc clutches have higher capacity than single-disc types by virtue of stacked alternating drive and driven discs, which increase the working friction surface.

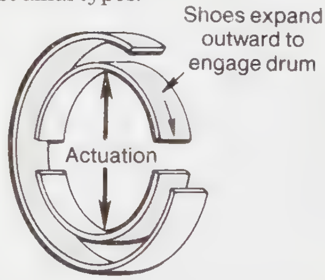
Simplest friction-type axial clutches. Conical pulley sheaves move axially to engage or disengage a belt drive. Suitable for light loads only. An even simpler variation (though not an axial type) uses a standard sheave mounted on a swinging arm to engage or disengage the belt.



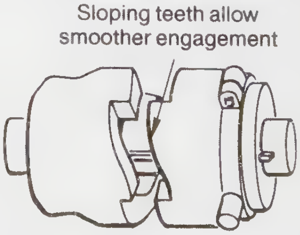




Drum: In expanding type, a set of shoes connected to one shaft expand outward to engage a rim or drum connected to the other shaft. In a contracting type, the shoes are carried by the outer rim and contract inward against a drum. The shoes are actuated mechanically, hydraulically, or pneumatically. The contracting type responds especially fast because centrifugal force helps withdraw the shoes rapidly. Thus, it is well suited to cyclic operation. Rim or drum-type clutches are easy to repair and maintain compared to most axial types.



Square jaw: Simplest and most basic clutch. Consists of square teeth which lock into mating recesses in facing member. Provides instant, positive lockup, but because it cannot slip, it will not engage safely if shafts are not stationary or turning at the same speed. Running engagements possible up to about 10 rpm. Available in sizes from 1 to 6 in. in ratings from 1 to 260 hp per 100 rpm.



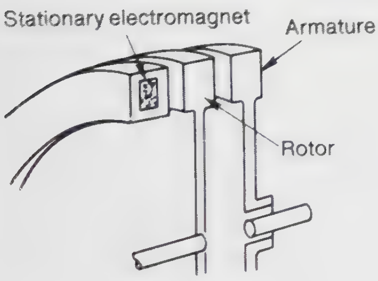
ELECTRIC CLUTCHES

Friction: Most widely used type. Basically a conventional disc-type mechanical clutch with electrical actuation. Upon actuation, an armature connected to the output shaft is pulled into contact with a magnetic coil attached to the input shaft. The mating surfaces of magnet and armature are covered with friction materials. In this design, called a rotating field clutch, collector rings (not shown) are required to carry current to the rotating magnet.

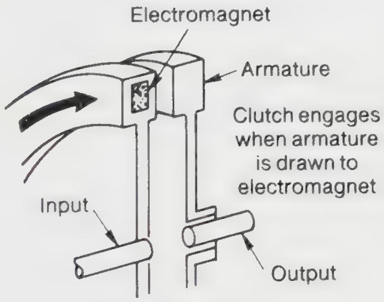
In the stationary field clutch, the magnetic coil is fixed (thus, collector rings are not needed), and the magnetic force draws the output armature to an input rotor.

Operating principle and applications similar to those of the single-disc type. Main difference is that interleaving of input and output discs provides greater friction area and, thus, greater torque capacity for a given clutch diameter. But a multiple-disc clutch cannot dissipate heat as readily and, thus, has a limited duty cycle if used in air. For this reason, most multiple-disc clutches are used in oil. As with single-disc clutches, the magnetic coil can be either rotating or stationary, but the stationary type is more common because it avoids slip rings and brushes.

SINGLE DISC



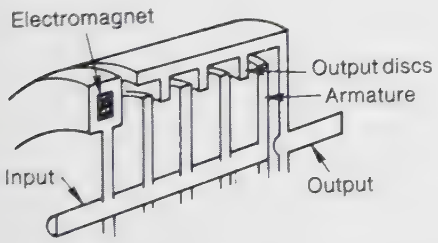
Stationary field



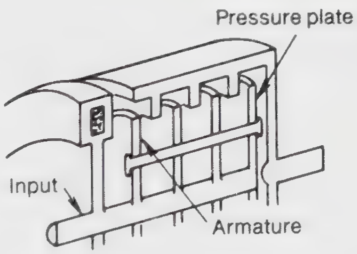
Rotating field

MULITPLE DISC

Multiple-disc clutches can be either direct acting or indirect acting. In the direct-acting type, the output discs are part of the magnetic circuit. In the indirect-acting clutch, the magnet acts on an armature which pulls discs into engagement through a pressure plate.

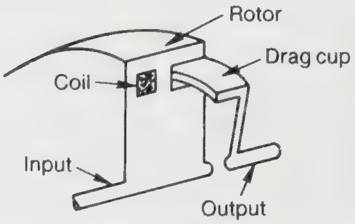


Direct acting



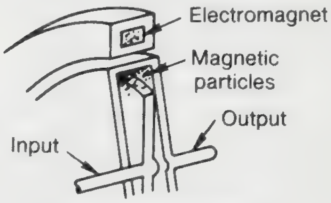
Indirect acting

Nonfriction: Coil on input rotor generates magnetic field in rotor and drag cup. Hysteresis loss sets up torque reaction in drag cup as rotor is turned. Torque is proportional to coil current.



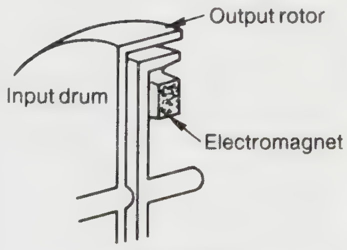
HYSTERESIS

Input disc is closely fitted within output housing that contains magnetic particles. When coil is energized, particles form a rigid bond between input disc and output housing to transmit torque.



MAGNETIC-PARTICLE

Coil sets up magnetic field that links input drum and output rotor. Eddy currents induced in input drum interact with magnetic field in output rotor, creating coupling torque proportional to coil current.



EDDY CURRENT

actuated clutches. For example, air can be channeled through a hand-operated throttle valve, allowing the operator to gain a feel for the amount of engagement. Also, air-actuated clutches can be operated through flow-control valves that engage the clutch over a specific time interval. Thus, acceleration of the output shaft can be smoothed over 100 to 150 ms.

In addition to remote control through hand-operated valves, air-actuated clutches can be operated automatically. Here, electric controls are incorporated to signal a solenoid valve to pressurize the clutch.

A possible disadvantage of air operation is the support equipment (compressor, valves, piping) which may increase space requirements and maintenance costs. Also, because air is exhausted to the atmosphere after each cycle, the pressurized air supply must be replenished constantly. Thus, system operating costs are increased by the need to run a compressor. The clutches themselves, however, are simple and durable, so clutch maintenance costs usually are not significant.

Electric clutches use two different operating principles. One type uses friction or tooth clutches engaged electrically and released by springs. The

Warner Electric UniModule®, one box, one piece,

Introducing UniModule... all the controllability of electric clutches and brakes in a one piece, C-face package. As easy to install as 1-2-3.

1 Slide UniModule onto motor shaft

Bolt-it-down,
wire-it-up

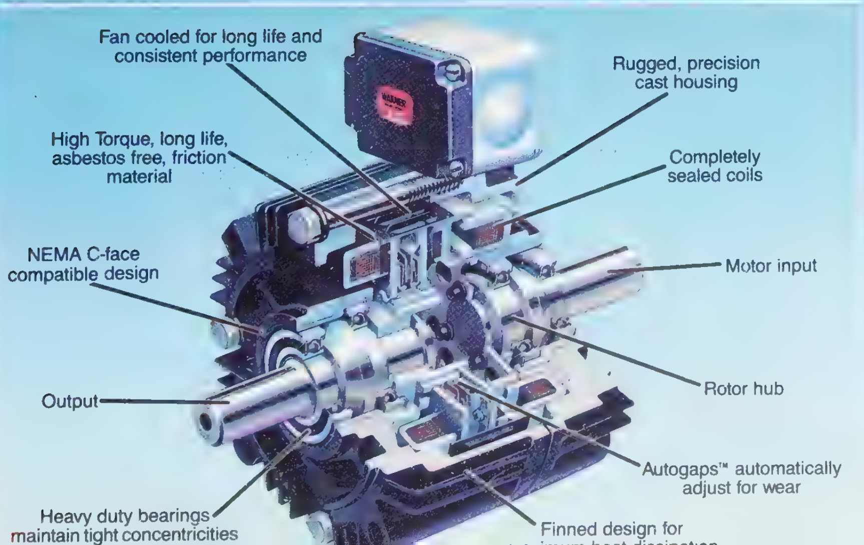
one minute...

2 Tighten two set screws

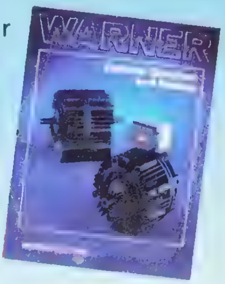
3 Tighten down 4 bolts

UniModule...the new clutch/brake package that's 7 ways better!

- 20 of the best clutch-brake components designed into a one-piece unit. UL listed, CSA certified.
- Factory aligned and run-in to provide rated torque out-of-the-box. High cycle duty, long life, rugged.
- 4 sizes, 22 models. C-face or foot mount.
- Built-in power supply or separate control system.
- Power actuated or fail safe.
- No maintenance. Automatic adjustment for wear.
- No installation problems. Bearing mounted rotor. Captive clutch key.


Fan cooled for long life and consistent performance
Rugged, precision cast housing
High Torque, long life, asbestos free, friction material
Completely sealed coils
NEMA C-face compatible design
Motor input
Output
Rotor hub
Autogaps™ automatically adjust for wear
Heavy duty bearings maintain tight concentricities
Finned design for

Available now, at more than 500 Warner Electric distributor locations. Complete engineering specifications in our new catalog, P-785. Send for your copy today.



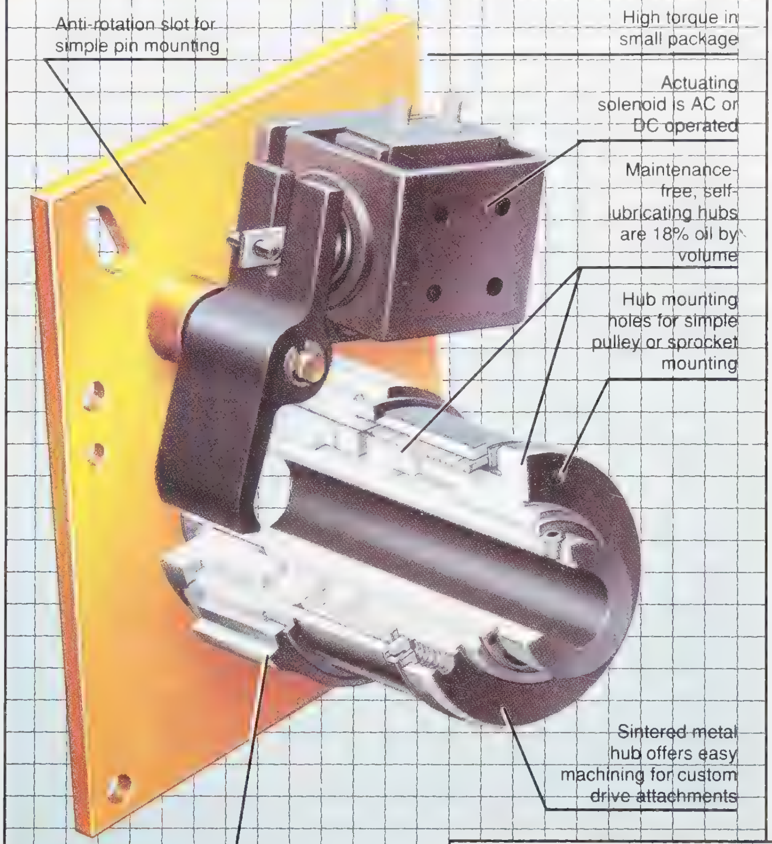
Write or call
Warner Electric
South Beloit, IL
61080
Call 800/234-3369
815/389-3771
Fax 815/389-2582

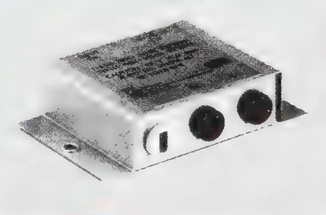
WARNER ELECTRIC

DANA

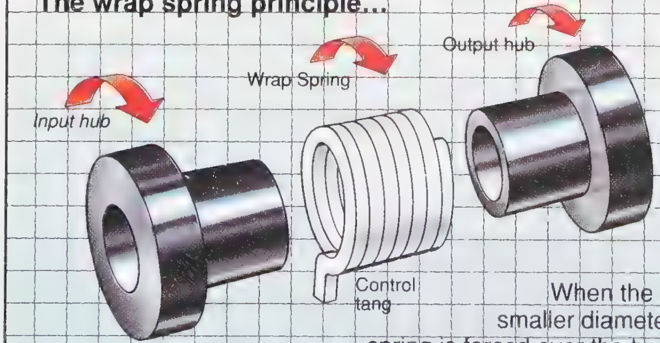
Circle 173

WARNER ELECTRIC
solenoid actuated wrap spring clutches


Anti-rotation slot for simple pin mounting
High torque in small package
Actuating solenoid is AC or DC operated
Maintenance-free, self-lubricating hubs are 18% oil by volume
Hub mounting holes for simple pulley or sprocket mounting
Sintered metal hub offers easy machining for custom drive attachments
Single or multi-stop collars control rotation


One Shot Power Supply

The wrap spring principle...



When the slightly smaller diameter wrap spring is forced over the two hubs, rotation in the direction of the arrow wraps the spring tightly to positively engage the hubs. The greater the force of rotation, the stronger the wrap spring's grip on the hubs. Rotation in the opposite direction opens the spring.

High torque, accurate positioning, wrap spring, clutch packages

☐ **High torque to size ratio**
Wrap spring clutches offer dramatic advantages in torque to size ratios as compared to many other torque control devices, such as hysteresis, magnetic particle and friction disc units. Torque ratings of 500 lb.in. result from units that are only 2.5 inches in diameter.

☐ **Fast acting, wide torque range**
The SAC Series clutches bring loads up to speed within 3 milliseconds. Available in four sizes with torque ratings from 25 lb.in. to 500 lb.in.

☐ **Wide range of control interfaces**
Electrically actuated. Easy interface to PC's and other controls including Warner Electric photoelectrics.

☐ **Accurate positioning**
Single stop per revolution standard. Multiple stop positions available. Adjustable stop collars allow the user to fine tune the stopping position for each application requirement.

☐ **Local service and stock availability**
Our customers are served promptly through a nationwide network of more than 500 distributor outlets.

Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog P-1017
815/389-3771
Fax 815/389-2582

WARNER ELECTRIC
DANA

Circle 174

WARNER ELECTRIC
Magnetically Actuated Spring Clutch

New, MAC-30 Clutch offers high performance at a low cost.

Years of experience in developing magnetically actuated clutches for paper transport drives are all wrapped up in the new, MAC-30 .. meeting the highest industry performance standards, at an outstanding price, using state-of-the-art engineering, materials and processes.

Features

Speed, durability, repeatability

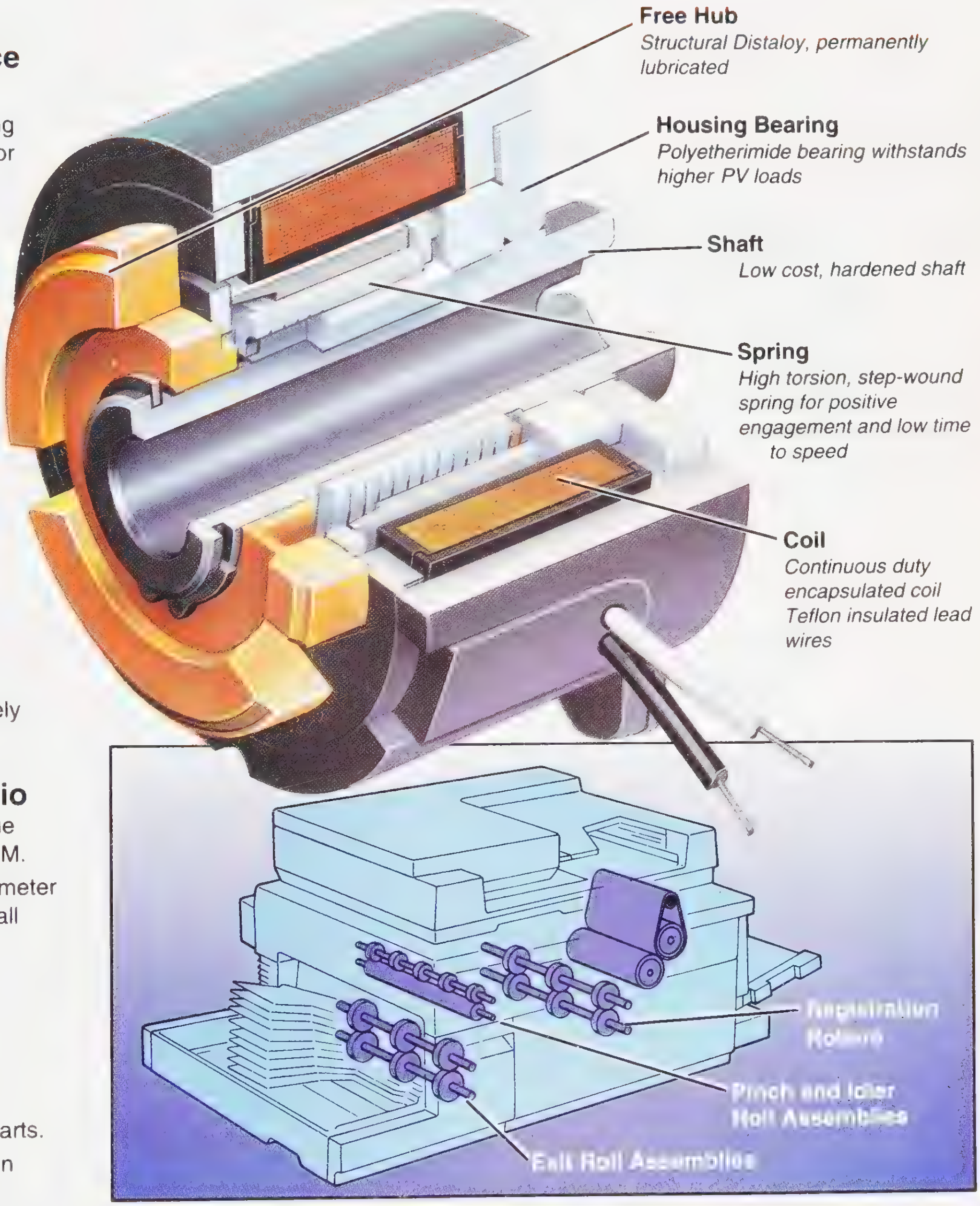
- Wrap spring technology allows for very fast response to bring loads up to speed within 50 milliseconds (less, depending on RPM).
- Exceeds industry life requirements with no cycle-to-cycle variation.
- Enclosed construction effectively eliminates contaminants.

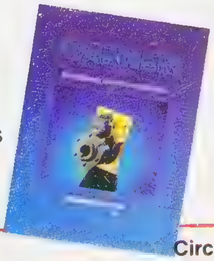
High torque-to-size ratio

- 25 in. lb. (2.83 Nm) static torque capacity at speeds to 1200 RPM.
- 1.180 inch (30mm) outside diameter and 1.055 inch (26.8mm) overall length

Simple operation, fewer problems

- Electrical actuation for simple, control interface.
- MAC-30 has only three main parts.
- Drag free, friction free operation results in less wear.


Free Hub
Structural Distaloy, permanently lubricated
Housing Bearing
Polyetherimide bearing withstands higher PV loads
Shaft
Low cost, hardened shaft
Spring
High torsion, step-wound spring for positive engagement and low time to speed
Coil
Continuous duty encapsulated coil Teflon insulated lead wires
Registration Rollers
Pinch and Idler Roll Assemblies
Exit Roll Assemblies



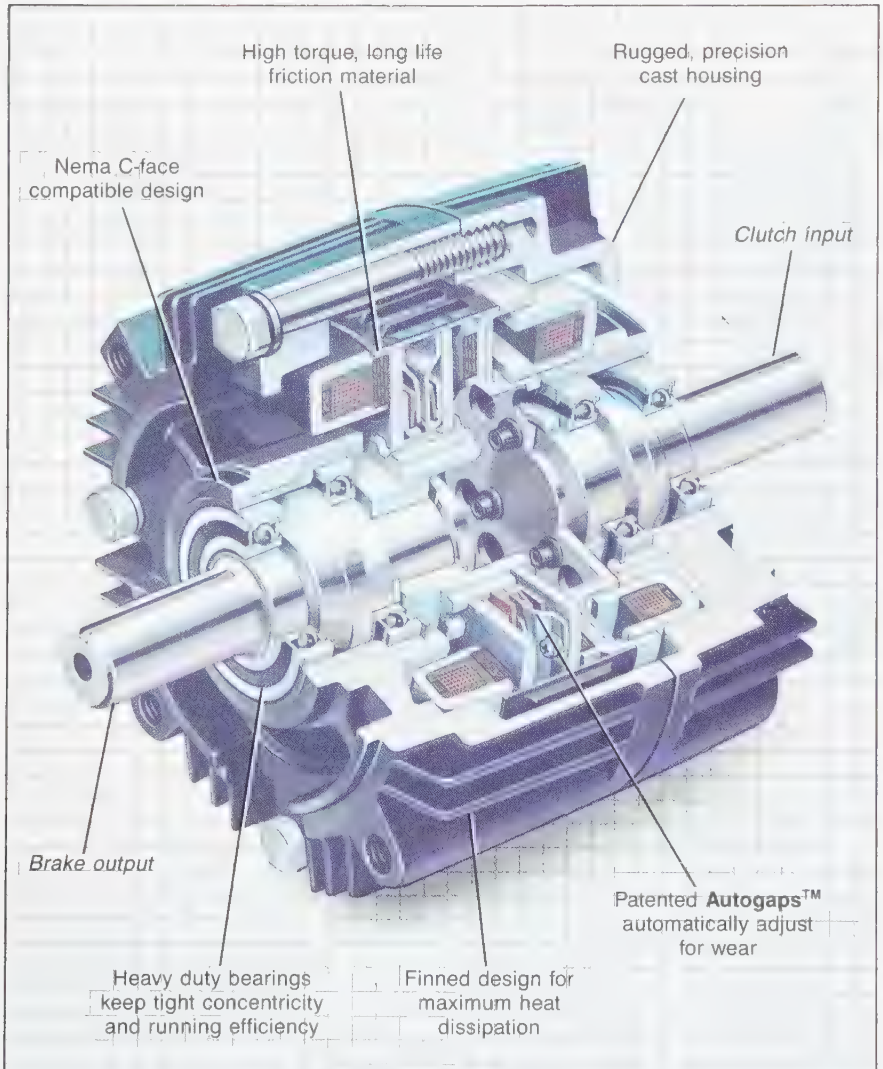
Ask for Catalogs
P-619 & P-1007

Write or call Warner Electric,
South Beloit, IL 61080
Call 800/234-3369
815/389-3771
Fax 815/389-2582

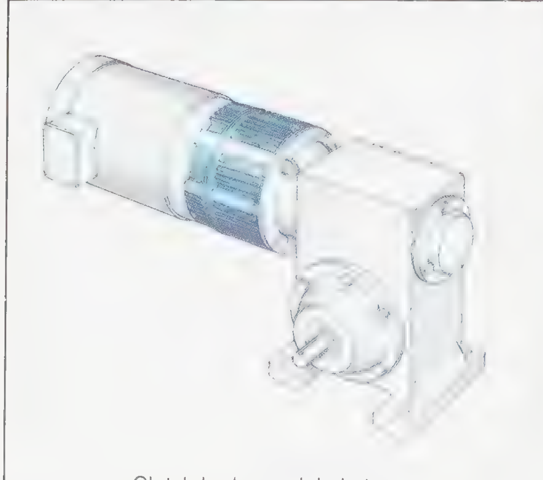
WARNER ELECTRIC
DANA

Circle 175

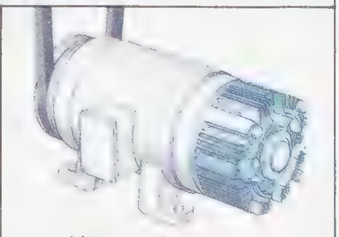
WARNER ELECTRIC clutches and brakes. . . rugged, fast, responsive control improves performance 5 ways!


High torque, long life friction material
Rugged, precision cast housing
Nema C-face compatible design
Clutch input
Brake output
Patented **Autogaps**™ automatically adjust for wear
Heavy duty bearings keep tight concentricity and running efficiency
Finned design for maximum heat dissipation

Bolt it down, wire it up
Electro Module is one of a family of factory assembled clutch and brake packages.



Clutch-brake module between Nema C-face motor and reducer



Motor brake module

Base mounted clutch-brake module

1. **Rugged**
Pre-engineered and pre-packaged for maximum performance • Long life components and materials

2. **Electric**
Electric actuation for fast, consistent response • Easily interfaced with machine electrical systems • UL and CSA listed

3. **Simple, trouble-free**
Clean, quiet and self-adjusting for wear • Never need lubrication or adjustment

4. **Electric/electronic torque control**
Standard controls give fully adjustable torque • Soft starts and stops • Rapid cycling

5. **Sized right, rated right, off-the-shelf**
No compromises on performance. With over 400 standard models and controls you can select a perfect match for each application requirement.

6. **Local service and stock availability**
Our customers are served promptly through a nationwide network of more than 500 distributor outlets

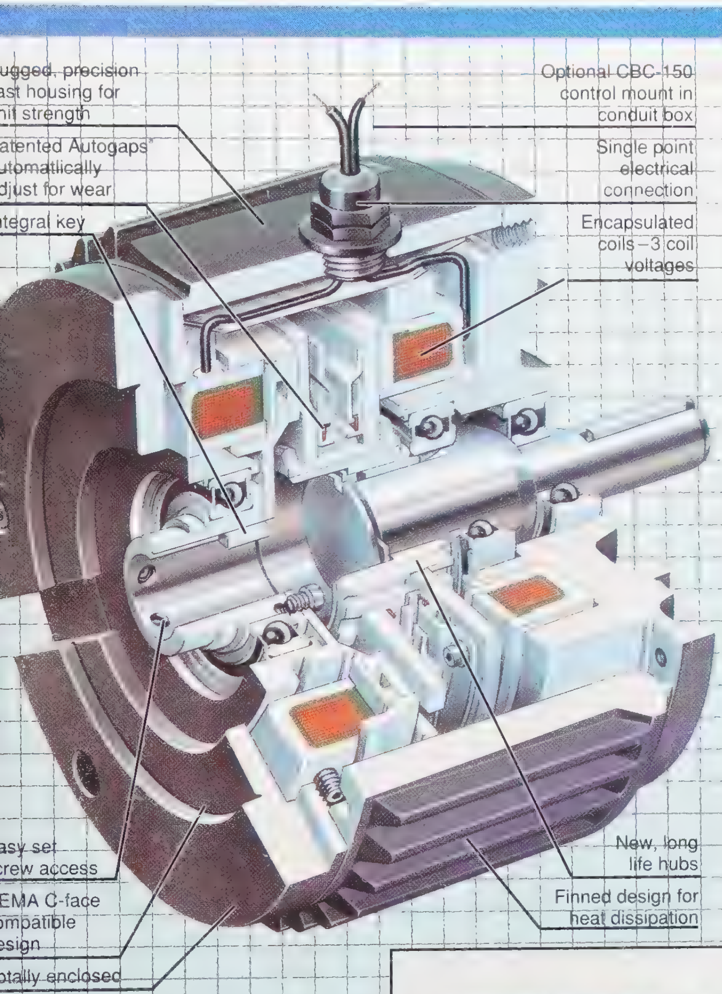
Warner Electric
South Beloit,
IL 61080
Call 800/234-3369
Ask for catalog P-785
815/389-3771
Fax 815/389-2582

WARNER ELECTRIC

DANA

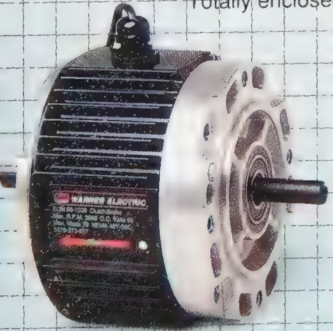
WARNER ELECTRIC

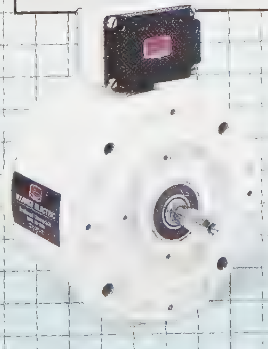
Enclosed UniModule®... One-piece electric clutch/brake package



CBC-1000 Position-loop control
Designed for clutch/brake indexing applications.

EUM series
Totally enclosed





EUM-W series
New Washdown Unit

Totally enclosed or washdown units

☐ **Enclosed protection**
Nothing can get in, nothing can get out. Enclosed design eliminates damage to the working components. Prevents friction residue from escaping.

☐ **One piece, C-face package**
Completely assembled and factory aligned. Mates easily with standard motors and reducers. Foot mounted package also available.

☐ **Meets washdown requirements**
EUM-W Series has been specially designed for washdown applications. Ideal for food processing and packaging applications.

☐ **Easy-to-install. No maintenance**
No installation problems. Bolt-it-down, wire-it-up. UniModule is ready to go. Automatic adjustment for wear.

☐ **Complete control capability**
Available with built-in power supply or used with separate controls for soft starts and stops...or for fast acting, accurate cycling.

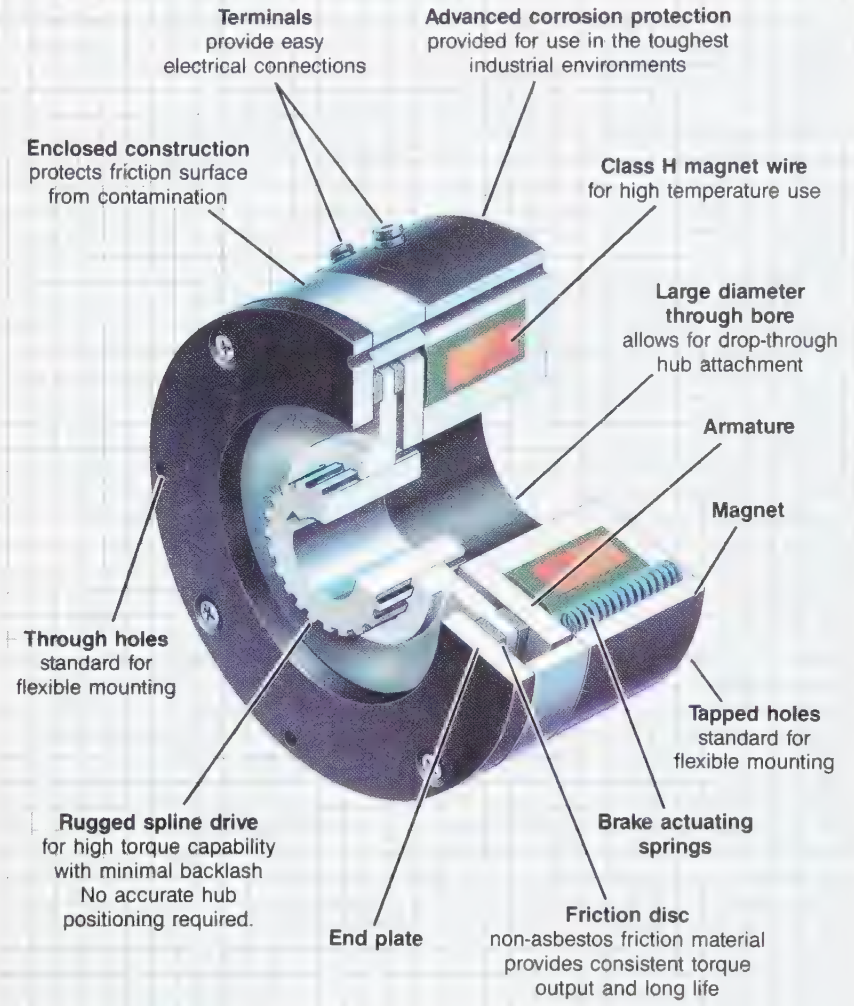
☐ **Local service and stock availability**
Our customers are served promptly through a nationwide network of more than 500 distributor outlets.

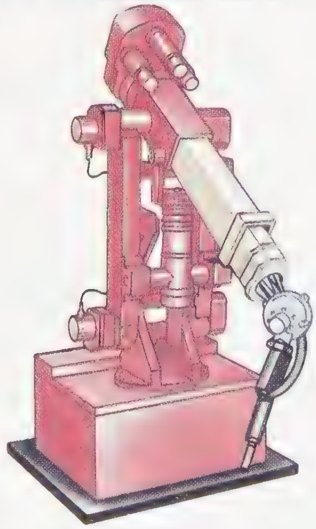
Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog P-1040
815/389-3771
Fax 815/389-2582

WARNER ELECTRIC
DANA

Circle 177

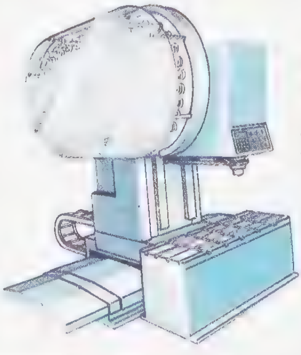
WARNER ELECTRIC fail safe brakes . . . quick, quiet, reliable, compact, electrically released, spring set


Terminals provide easy electrical connections
Advanced corrosion protection provided for use in the toughest industrial environments
Enclosed construction protects friction surface from contamination
Class H magnet wire for high temperature use
Large diameter through bore allows for drop-through hub attachment
Armature
Magnet
Through holes standard for flexible mounting
Tapped holes standard for flexible mounting
Rugged spline drive for high torque capability with minimal backlash No accurate hub positioning required.
Brake actuating springs
End plate
Friction disc non-asbestos friction material provides consistent torque output and long life



Robotics
ERS Brakes maintain wrist, shoulder, elbow and base positions on multi-axis robots

Medical Equipment
Wheel chairs, surgical equipment, and x-ray equipment



Machine Tools
Used on automatic tool changers to hold the load and maintain precise positioning

Highly reliable

Warner Electric ERS fail safe brakes are ideal for use as a holding brake in applications where the motor is used to accurately position the load.

Packaged product

Pre-assembled and factory aligned. Each unit is checked to insure full rated torque right out-of-the-box.

Easy to control

Springs assure reliable, positive engagement of the brake friction surfaces. No power required to hold the load. Electromagnetically released.

Easy to install

No maintenance

Rugged splined drive hub available for common shaft sizes. Optional mounting flange expands installation possibilities. Bolt-it-down, wire-it-up, you're ready to go. No adjustments for the life of the unit.

Local service and stock availability

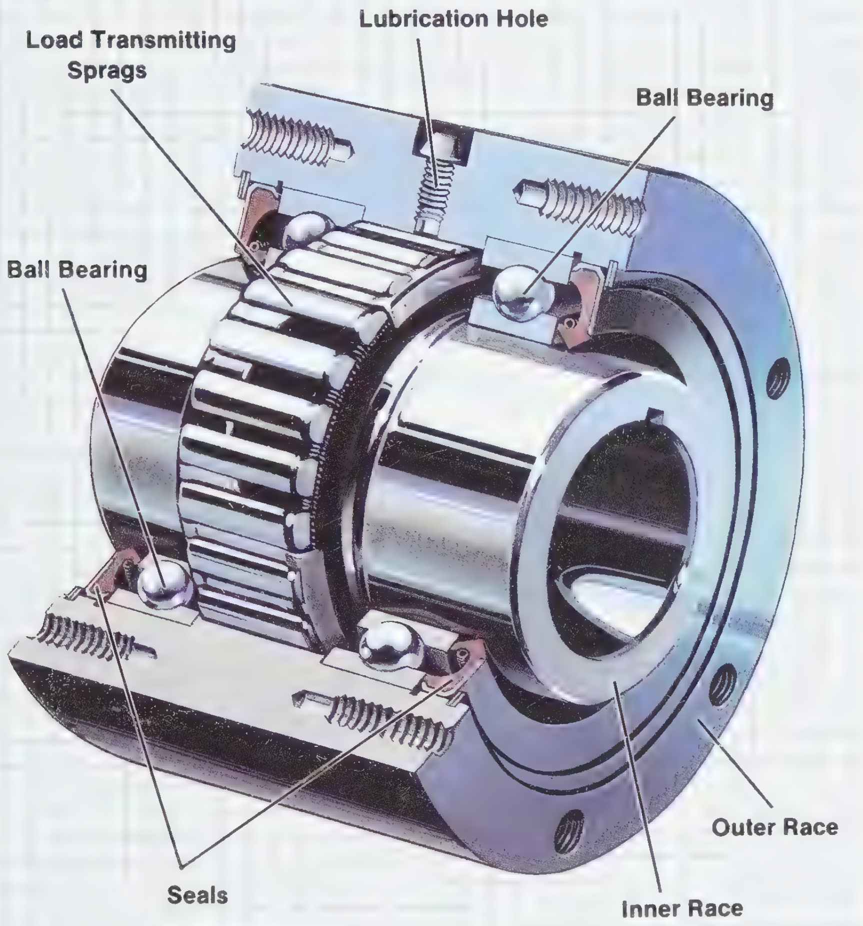
Our customers are served promptly through a nationwide network of 850 distributor outlets.

Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog P-873
815/389-3771
Fax 815/389-2582

WARNER ELECTRIC
DANA

Circle 178

FORMSPRAG® Over-Running clutches... instantaneous action, no backlash, high torque, compact, reliable



1. Simple, reliable principle
Accurately formed sprags, held within cylindrical inner and outer races, drive in one direction and overrun or free-wheel in the other direction. Wedging action of sprags transmits torque from one race to the other.

2. Three basic application types
- Simple overrunning...used in standby and compound drives
- Indexing, with reciprocating input and uni-directional output
- Backstopping or holdback to prevent reverse rotation of drives, such as inclined conveyors.

3. Wide range of models
• High torque in a small package • 17 basic configurations • Torque range of 4.5 lb.ft. to 560,000 lb.ft.• Shaft sizes available from .250" to 20"

4. Available design features
• Free-action retainer insures even load distribution • Centrifugal throwout retainer assemblies eliminate rubbing contact and wear during long periods of high speed overrunning • Ultra-hard Formchrome® sprags to extend clutch service life • PCE® sprags overcome effects of severe vibrations and high torque overloads.

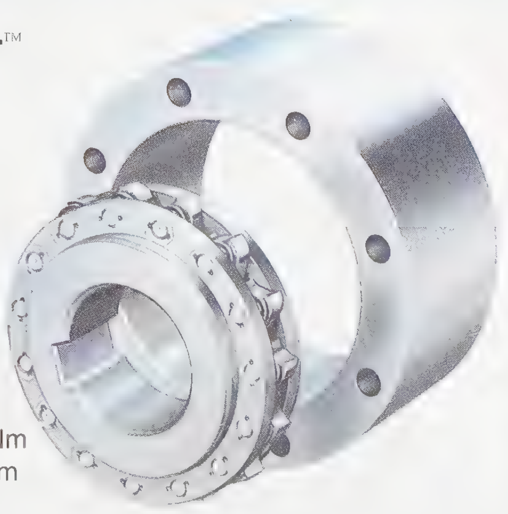
5. Local service and stock availability
Our customers are served promptly through a nationwide network of more than 500 distributor outlets.

Formsprag®-Stieber™ Over-running Clutches

Sprag and Roller-Ramp Design

Overrunning, Indexing, High Speed Backstops, Clutch-Couplings

- Narrow and extra narrow metric series
- Torque from 1 to 136,000 Nm
- Bore sizes from 6 to 320 mm



Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalogs
P-956 and P-935
815/389-3771
Fax 815/389-2582

WARNER ELECTRIC

DANA

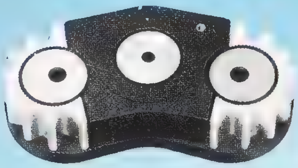
Circle 179

WARNER ELECTRIC
Electromagnetic Tension Brakes

Warner Electric announces MTBII . . . the second generation. A new, improved design, with all the smoothness and controllability that helped make the MTB brake an industry standard . . . plus longer life, cooler operation and new sizes to choose from.

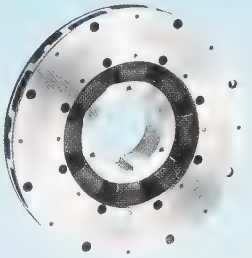
2 to 3 times more life!

Years of testing have produced a unique, patented design offering more than double the life...without any loss in smoothness or controllability. Now available in 10", 13", 15" and 20" diameters, 44 modular combinations, and torque ranges to 1120 lb./ft. to help you precisely match the right brake to your application.



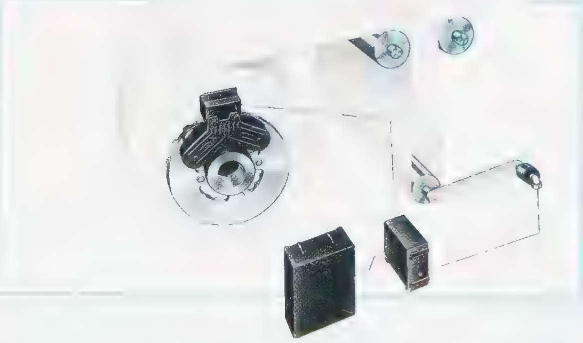
New, electronic wear option

Indicator imbedded in the magnets alerts control to signal when 15% brake life remains.



Reduced inertia

New, armature design features a radial blower concept to improve air flow and cooling. Systems run cooler and last longer. Aluminum armature carrier reduces inertia up to 40%...improves controllability.



Complete tension control systems

Dancer and analog control systems. Complete, closed loop control capability. Fast response and consistent control from full roll to core.

Available now at more than 500
Warner Electric distributor locations.
Call or write
Warner Electric, South Beloit, IL 61080
800/234-3369
Ask for Catalog P-771.
815/389-3771 • Fax 815/389-2582

WARNER ELECTRIC

DANA

Circle 180

WARNER ELECTRIC
High Performance Air Tension Brakes

Warner Electric announces AIR DISC...the air solution. A new improved concept in air brake design, with all the torque and thermal capacity you'd expect in an air actuated device, and the system controllability that's made Warner Electric the industry standard.

High heat horsepower

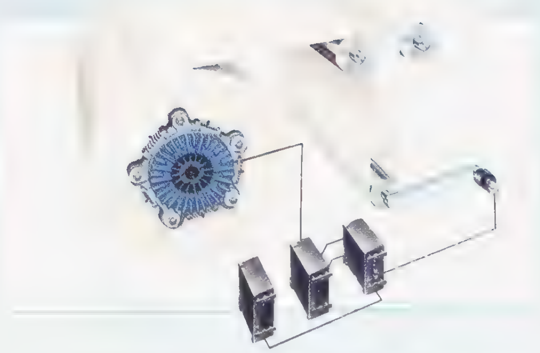
Thermal capacities up to 28 horsepower in normal operating speed ranges. Three size ranges, 10" 13" and 16", with 19 different modular combinations. Torque ranges to 10,200 lb./in. to handle your toughest job.

Optional integral guard system

Optional guard affords your operator the protection he deserves, without the hassle of additional engineering and sourcing.

Local availability

Warner Electric's extensive network of technical distributors supported by local factory representatives gives you not only a local source for parts, but the engineering expertise you need to protect your investment.



Complete tension control systems

Dancer, Analog, Load Cell, and PC interface systems provide you with the right option for any application.

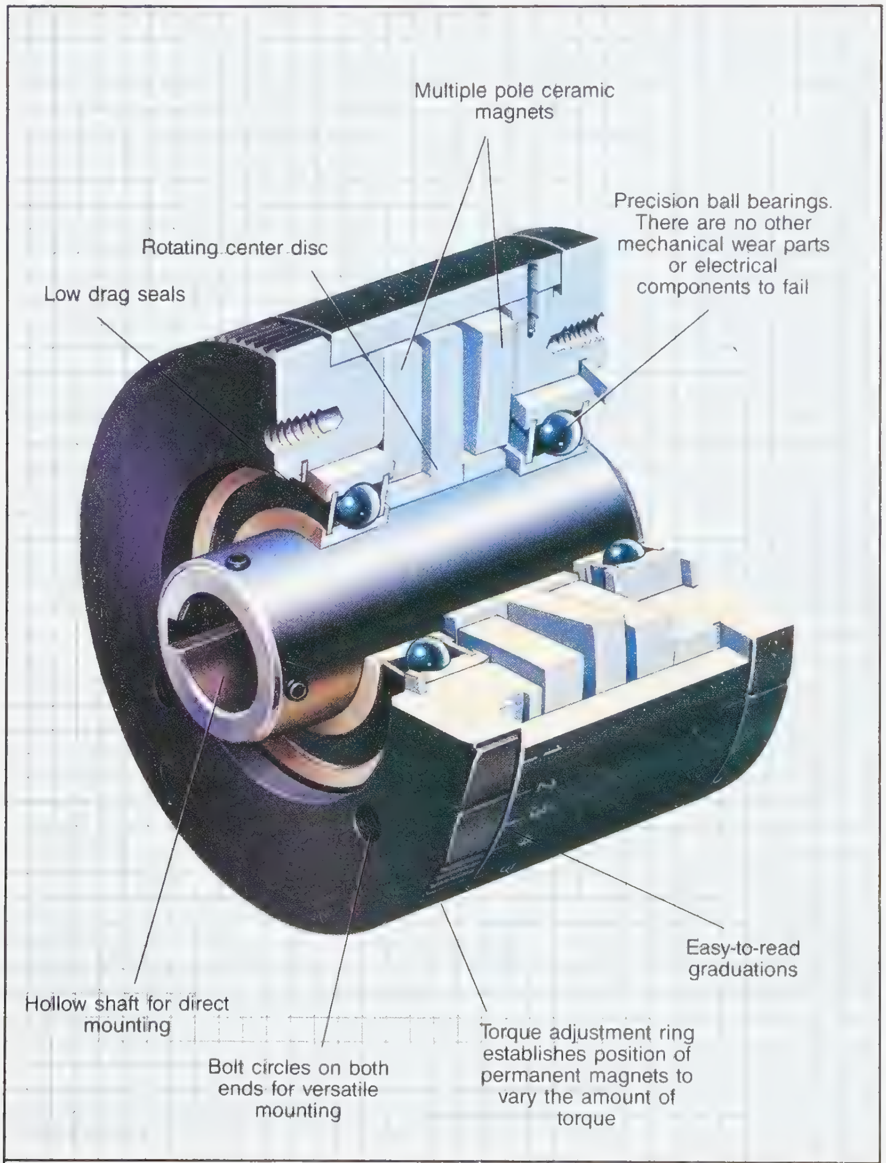
Available now at more than 500
Warner Electric distributor locations.
Call or write
Warner Electric, South Beloit, IL 61080
800/234-3369
Ask for Catalog P-1015
815/389-3771 • Fax 815/389-2582

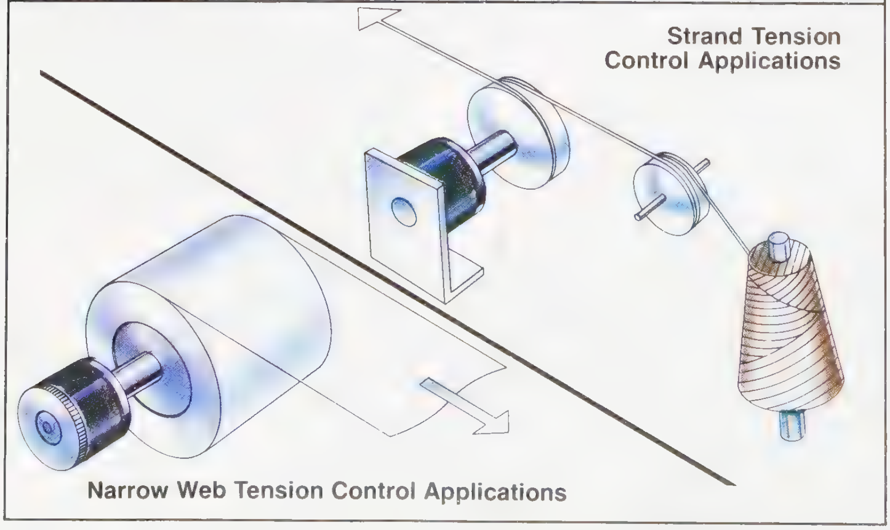
WARNER ELECTRIC

DANA

Circle 181

FORMSPRAG® Perma-Tork® permanent magnet clutches and brakes . . . smooth accurate, reliable, long life


Multiple pole ceramic magnets
Precision ball bearings. There are no other mechanical wear parts or electrical components to fail
Rotating center disc
Low drag seals
Easy-to-read graduations
Hollow shaft for direct mounting
Bolt circles on both ends for versatile mounting
Torque adjustment ring establishes position of permanent magnets to vary the amount of torque


Strand Tension Control Applications
Narrow Web Tension Control Applications

1. Two basic design types
Hysteresis design provides constant torque independent of slip speed. Eddy current type provides variable torque proportional to slip speed.

2. Reliable consistent performance
Permanent magnets provide smooth, repeatable, accurate, torque control. Extremely accurate, even on low end of range. Sizes from .10 oz. in. to 55 lb. in. of torque. Easy-to-set adjustment ring establishes precise torque.

3. Long life—power free
No friction elements. No external power source required. Only two moving parts.

4. Wide range of applications
Perma-Tork brakes are ideal for tensioning, overload protection and torque limiting applications. Easily adjusted to slip at a desired torque. As a magnetic coupling, Perma-Tork clutches are capable of providing extremely smooth, soft starts.

5. Local service and stock availability
Our customers are served promptly through a nationwide network of more than 500 distributor outlets.

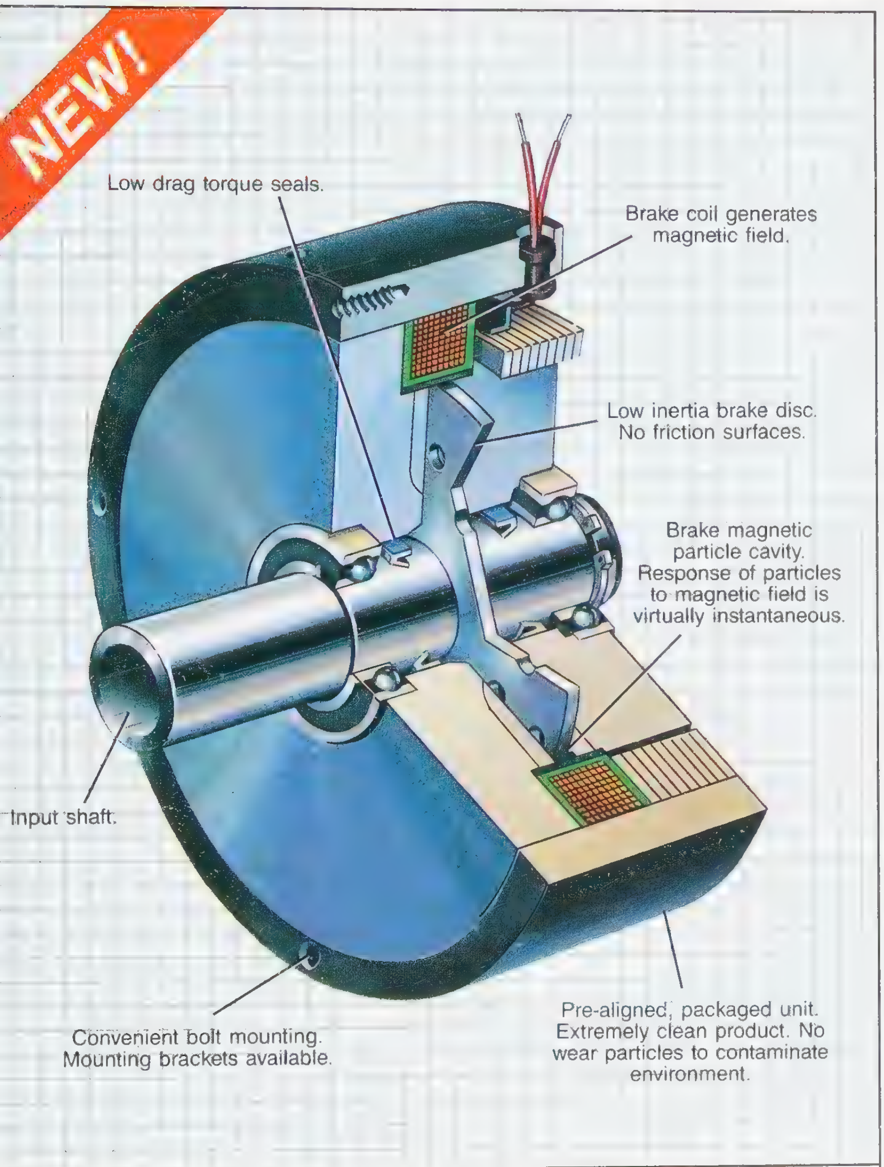
Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog P-930
815/389-3771
Fax 815/389-2582

WARNER ELECTRIC

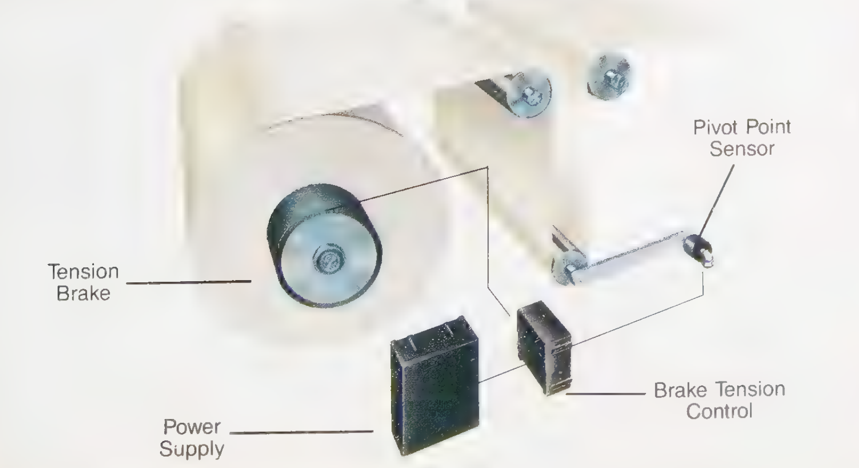
DANA

Circle 182

FORMSPRAG® magnetic particle clutches and brakes . . . extremely fast response, smooth, precise torque control


NEW!
Low drag torque seals.
Brake coil generates magnetic field.
Low inertia brake disc. No friction surfaces.
Brake magnetic particle cavity. Response of particles to magnetic field is virtually instantaneous.
Input shaft.
Convenient bolt mounting. Mounting brackets available.
Pre-aligned, packaged unit. Extremely clean product. No wear particles to contaminate environment.

Dancer Arm Control Systems



1. Fast response— High cycle rates

No friction surfaces to move. Rapid response to signal changes. Cycle rates of more than 1000/minute are possible.

2. Precise control

Torque output is directly proportional to current input. Infinitely variable from zero to rated torque. Torque output is independent of slip speed. Very smooth and repeatable.

3. Quiet and clean

No wear particles to contaminate surrounding environment. No engagement slap or squeak. Totally enclosed, packaged unit.

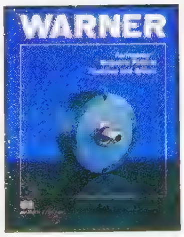
4. Smooth and consistent torque control

Formsprag magnetic particle clutches and brakes are widely used to provide consistently smooth tension control. A superior product for applications requiring gradual, smooth engagement.

5. Local service and stock availability

Our customers are served promptly through a national sales staff and distributor network.

Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog P-931
815/389-3771
Fax 815/389-2582

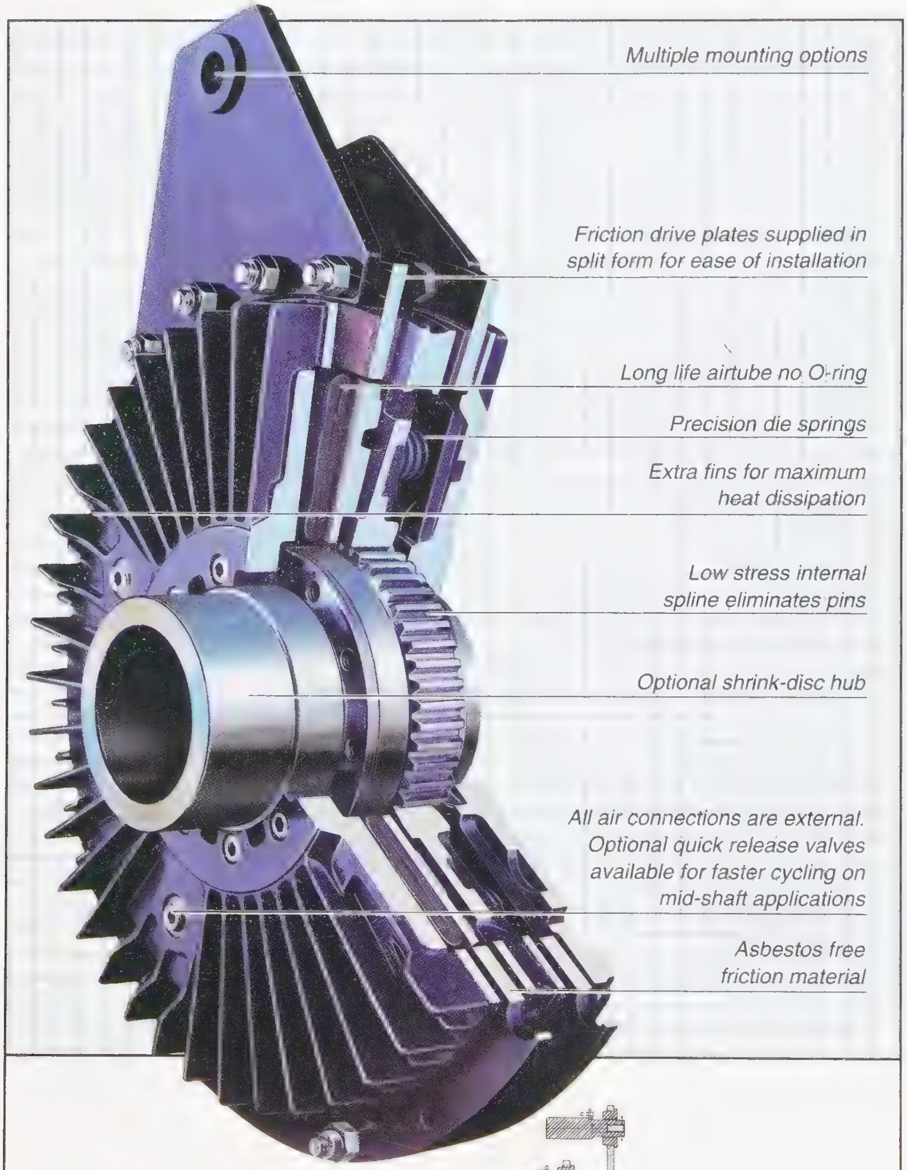


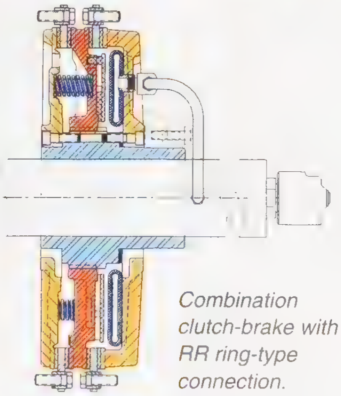
WARNER ELECTRIC

DANA

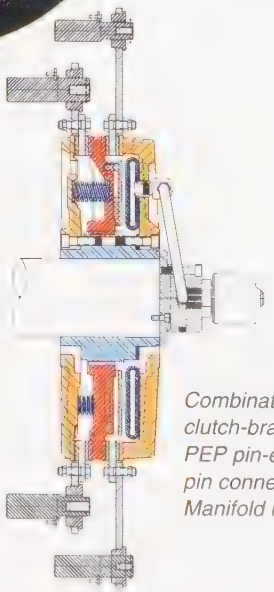
Circle 183

WICHITA® Clutches/Brakes... combination package, compact disc design for fast smooth cycling


Multiple mounting options
Friction drive plates supplied in split form for ease of installation
Long life airtube no O-ring
Precision die springs
Extra fins for maximum heat dissipation
Low stress internal spline eliminates pins
Optional shrink-disc hub
All air connections are external. Optional quick release valves available for faster cycling on mid-shaft applications
Asbestos free friction material



Combination clutch-brake with RR ring-type connection. Mid-shaft shrink disc mounting.



Combination clutch-brake with PEP pin-extended-pin connection. Air Manifold mounting.

Unique design

Simple Wichita air tube concept combines an air actuated clutch and a spring-set brake in a compact disc design. Provides fast, smooth cycling for stamping presses and metal forming equipment.

Wide range of models

Eight models of both english and metric units. Torque ratings to 540,600 lb.in. (66,000Nm). Heat dissipation capacity up to 18 horsepower at 900 RPM.

Easy to install

Combination clutch/brake package eliminates assembly guesswork. Designed for easy installation on both new and existing presses.

Experience

Over 40 years of experience in designing and manufacturing air-tube disc clutches and brakes. Today, we are recognized as a global leader in heavy-duty power transmission.

Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog WIC-013
815/389-3771
Fax 815/389-2582

For application assistance contact
Wichita Clutch
817/767-2000 • Fax 817/767-5714

WARNER ELECTRIC

DANA

Circle 184

other type uses electric methods to engage input and output shafts without direct mechanical connection.

Electrically actuated clutches permit extremely fast cycling times (over 1,600 times per minute in some applications), but they do not provide the torque range of air or hydraulic clutches. Electric clutches are more convenient for automatic machinery where control commands come as electric signals rather than as pedal or lever motions. Electric actuation also works better where the clutch is far removed from the control point and where mechanical linkages or pneumatic or hydraulic piping would be too cumbersome or expensive.

Some types of electric clutches provide closely controlled rates of continuous slip that would quickly wear out mechanical clutches. On the other hand, electric clutches do not provide the "feel" of engagement common to mechanical clutches.

The greatest advantage of electric actuation is the extremely fast response possible. For example, some of the smaller diameter clutches can respond in 1 to 2 ms. In many cases it is easier to wire an electric clutch than to pipe a pneumatic or hydraulic one. Also, various types of control switches are easily added to the circuit, permitting control by a variety of inputs such as photoelectric impulses, magnetic flux, and temperature.

In friction and tooth clutches, an electromagnet or solenoid replaces hand-operated levers and air or hydraulic pistons. The coil is stationary or rotates with the clutch. These clutches generally are used for full-engagement and minimal-slip requirements.

Nonfriction clutches, such as hysteresis, eddy current, and magnetic particle, often operate with continuous slip but can lock up if required torque is less than the clutch torque capacity. Slip is controlled electrically to produce special operating characteristics.

Of the two types, electromagnetic clutches respond more quickly, and transmit higher torques. On the other hand, noncontact clutches do not wear, and they dissipate heat better.

Hostile environments may be a deterrent to using electrically actuated clutches. For example, most electric clutches run dry and, therefore, do not have high thermal capacities. Thus, they may perform erratically at high

ELECTRIC BRAKES

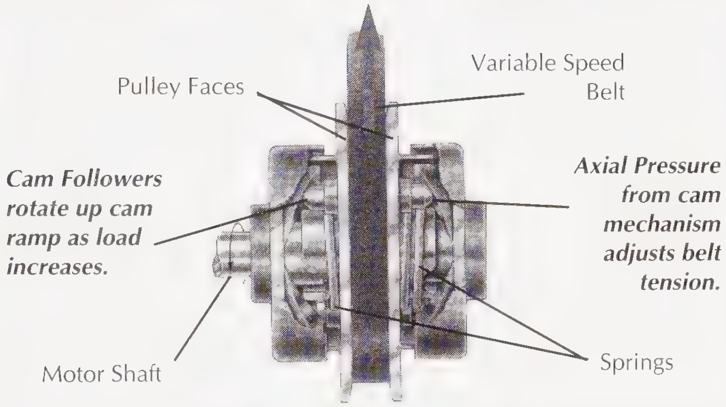
Friction: Operate in a fast, positive manner. When they are actuated, they bring the load to a full stop. When released, they offer little or no residual drag. These brakes are essentially mechanical brakes actuated electrically.

Electric friction brakes can be operated in one of two ways. An electrical force can be used to apply the brake, and a spring then returns it to disengagement when the force is removed. Or the brake can be actuated by pressure from a spring or permanent magnet, with the electrical force used to disengage the brake.

The spring or magnet-actuated types are fail-safe; if the power fails, the brake sets until power is restored.

continued on page 148

THE SECRET TO A BETTER DRIVE...


Pulley Faces
Variable Speed Belt
Cam Followers rotate up cam ramp as load increases.
Axial Pressure from cam mechanism adjusts belt tension.
Motor Shaft
Springs

...AUTOMATIC BELT TENSIONING.

Exclusive Cam Mechanism

Only **Hi-Lo Variable Speed Pulleys** are built with our ingenious cam mechanism which automatically regulates required belt tension to achieve optimum drive performance. Increased loads cause our pulley faces to clamp down on the belt to effectively transmit the load without slippage, loss of pitch diameter or drive ratio. When load requirements decrease, **Hi-Lo Variable Speed Pulleys** back off the pressure because less energy wasting belt tension is needed to transmit the load. You'll see better performance, without the rapid component wear that comes from slippage or excessive belt tension.

hi-lo

Additional Bearing Support
- The peripheral support of the cam followers reduce pressure and wear on the sliding face bearing surface.
- The necessity of torque carrying keys in the pulley shaft and slide face are eliminated, resulting in full bearing surface contact.

Maintenance Free Bushings

Not merely oil impregnated, our high load carrying bronze bushings have an exclusive self-lubricating design. Routine speed-range maintenance cycles, as well as other fretting and corrosion problems are virtually eliminated.

Hi-Lo Manufacturing

612 / 566-2510 fax: 612 / 566-0562
1700-G Freeway Blvd., Mpls., MN 55430

Send for our catalog detailing drives engineered for 1/2 HP to 100 HP applications, or look us up in the '91 Thomas Register Catalog Section

Circle 185

continued from page 147

The most widely used electrical brake is the so-called disc brake. Its principle of operation, however, is not like that of a common mechanical caliper disc brake. The electrical disc brake, instead, is similar in operation to a disc or plate clutches or a plate disc brake. Energy is absorbed by having a rotating plate engage the flat face of a mating plate or disc.

As with clutches, electrical disc brakes are available in single-disc or multiple-disc varieties. The multiple-disc type has greater capacity provided that there is adequate cooling. The multiple-disc type generally is more costly than the single-disc type.

For brakes actuated electrically, the operating principle is identical to that of an electric disc clutch. In spring-actuated disc brakes, a spring-loaded pressure plate is pressed against a rotating friction disc until a magnet or solenoid forces it to retract. The torque or braking force in the actuated state usually can be adjusted.

The spring-actuated brake is available in either direct-acting or linkage-actuated types. A direct-acting brake has fewer moving parts and responds more rapidly. It uses a powerful magnet that pulls directly on the pressure plate armature.

In addition to disc-type brakes, there also are shoe (or drum) type electric brakes. Again, these are similar to the mechanical drum or shoe brakes. Compared to electrical-disc types, electrical shoe brakes are used for heavier loads because they have greater thermal capacity. But the shoe brakes are more costly and are harder to put in a protective enclosure. They also are more bulky and need more frequent adjustment because of brake-shoe wear.

The linkage-actuated brake is usually a shoe type and uses a relatively small solenoid acting through a linkage that provides enough mechanical advantage to release the brake.

Hysteresis: Provide constant torque (braking force) for a given control current. Torque is independent of speed up to high speeds. Torque is a linear function of control current except at low currents or near magnetic saturation. Thus, precise control is the main virtue of the hysteresis brake. This type has virtually no wear and almost unlimited life, but if used at high slip may overheat and require derating. These brakes are used primarily in fractional horsepower applications.

Eddy current: Have no holding power and are used only for drag load. The most common application is in adjustable-speed drives. They tend to run hotter than other nonfriction brakes and sometimes require special cooling provisions.

Magnetic particle: Require less control current than hysteresis type for the same holding torque. They provide considerable holding power at zero speed. However, they tend to generate considerable heat during slip and have limited thermal capacity.

When it comes to jacks we wrote the book.

Asking for our free technical brochure on machine and ball screw jacks comes with a decided benefit. You can get, free, the industry's most useful and comprehensive design and specification manual.

New, and notebook style, the manual is fully tabulated by category of interest. It's comprehensive, full of specifications, jack operating characteristics, design techniques and new products. In all, it will give you the decided edge on designing and specifying Pow-R-Jac jacks and jack systems from ¼ to 250 ton capacities.

And should you require it, we'll also back you with worldwide sales, manufacturing and engineering support. Just write, call, telex or fax for our free full-color brochure and find out how to get "The Book" free.

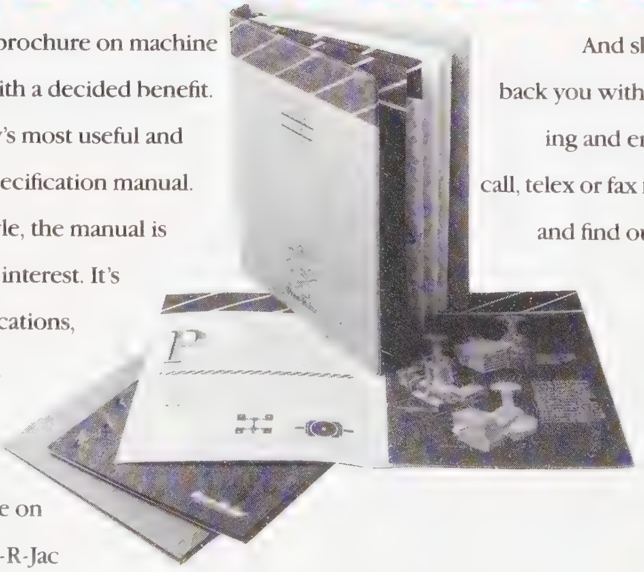
LIMITORQUE
POW-R-JAC CORPORATION

P.O. Box 11318
Lynchburg, Virginia 24506

Telephone: (804) 528-4400
Telex: 82-9448
Fax: (804) 845-9736

Pow-R-Jac
Division of Limitorque Corporation

Circle 186



HIT THE MARK!

AGAIN and AGAIN and AGAIN and AGAIN ... AGAIN

When you need consistent, accurate positioning day after day after day for cycling and indexing applications you need . . .

FORCE CONTROL

OIL SHEAR
Clutch and Brake Systems

Accurate Positioning . . .

The fluid absorbs and transfers engagement heat from the friction surfaces to the housing keeping the surfaces cooler than typical dry friction units.

Cooler friction surface operation results in less torque fade and improved positioning accuracy and consistency.

The fluid also helps to maintain a more stable operating environment for more consistent performance.

Improved Service Life . . .

The fluid provides lubrication between the working surfaces. Lubricated surfaces have a significantly lower rate of wear than non-lubricated surfaces.

Cushioned engagements inherent to Oil Shear design reduce shock to the entire drive train.

2-YEAR WARRANTY AVAILABLE

Contact us today for a FREE catalog containing specifications, engineering & selection information for our complete line of Oil Shear Clutch and Brake Systems.

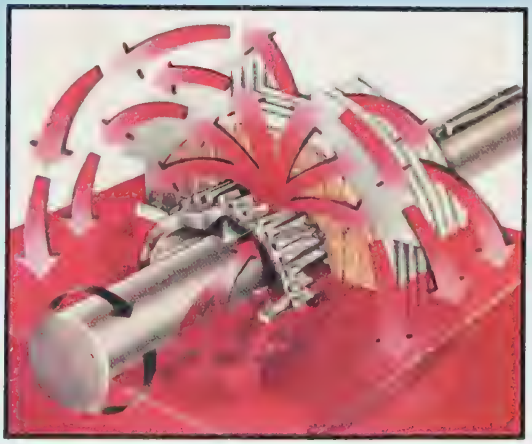
Posidyne®
CLUTCH and BRAKE

Posistop®
MOTOR BRAKE

Positorq®
TENSION BRAKE

Fluid Recirculation System

The Patented Fluid Recirculation System pumps the fluid into the center of the hub and out radially between multiple friction surfaces. Dynamic torque is transmitted by shearing the fluid between the friction surfaces. The fluid serves to lubricate the friction surfaces for reduced wear and also transfers engagement heat away from the friction surfaces for improved unit performance.



FORCE CONTROL

FORCE CONTROL INDUSTRIES, Inc.
3660 Dixie Highway Fairfield, Oh. 45014
Phone (513) 868-0900, Fax (513) 868-2105

DESIGN and ENGINEERING ASSISTANCE
(CALL TOLL FREE)
1-800-869-3244

A leader in Oil Shear technology for over 20 years.

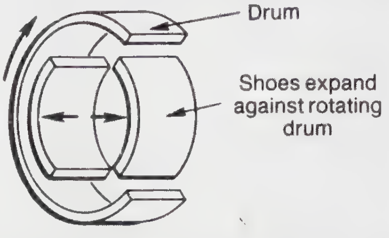
Circle 187

MECHANICAL BRAKES

Drum: The most common type of brake on automobile rear wheels. Shoes are expanded outward against a rotating drum. In a variation of this type, the shoes contract inward against a drum. Most drum-type brakes are of the fixed-anchor variety where the shoes have a fixed fulcrum. Floating-shoe brakes have no fixed fulcrum for the shoes.

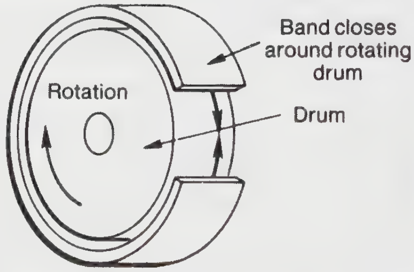
Fixed-anchor brakes may be one of three types: 1. Two-leading shoe type, where shoe actuation in the direction of drum rotation helps apply braking actuation force. 2. Two trailing-shoe type, where shoe actuation against drum rotation does not contribute to actuation force. 3. One leading and one trailing shoe type, which is not direction sensitive. Types 1 and 2 are sensitive to the direction of rotation.

The assist in actuation force, called self-energization, allows easier application of the brake but contributes to unsteady response. (The brake may "run away" and lock when only light braking is wanted.) Duo-servo brakes use two leading shoes in series where the braking force developed by a primary shoe becomes the actuating force for a secondary shoe. The result is very high self-energization. A compromise is the system using both leading and trailing shoes inside the same drum.



In a floating-shoe arrangement, one shoe has maximum self-energization. Although the braking force is divided equally between the shoes, the leading shoe carries a much greater portion of the load.

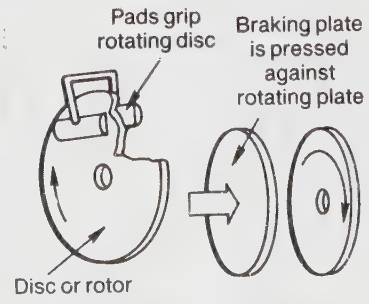
Band: The simplest type of mechanical brake. A flexible steel band, usually lined with friction material, is tightened around a rotating drum. The band is usually tightened by mechanical linkage, but it can be actuated electrically, pneumatically, or hydraulically. The stopping power of band-type brakes is not great, and they are commonly used as parking brakes to lock shafts that are already stationary. If the operating pull on the band is in the direction of rotation, the brake is self-energizing; that is, it uses shaft motion partially as an actuating force.



Disc: Generally considered the best performing and most fade-resistant brake. The most common disc brake is the caliper type, widely used on aircraft, automobiles, and in industrial applications. Caliper disc brakes are less susceptible to fade because heat can be dissipated easily from the disc or rotor and because thermal expansion does not decrease actuation pressure as in a drum-type brake. Disc brakes also are relatively unaffected by contamination from dirt or water.

Disc brakes offer no self-energization, but this can be an advantage in that response is more predictable without that feature. Disc brakes require high actuation pressure and, thus, are often used with power assist. Because the caliper pads are small and unit loading is high, special wear-resistant pad materials are required.

Plate-type disc brakes are similar in operation to disc clutches. In brakes, the plate type usually has multiple discs. This configuration provides high braking force in a small package, but it cannot dissipate heat well and may tend to overheat if cycled frequently.



CALIPER PLATE

temperatures. Because friction clutches sometimes spark due to metal-to-metal contact, they should not be used in explosive atmospheres.

Hydraulically actuated clutches deliver higher torque per unit volume than any other clutch. With this high capacity, hydraulically actuated clutches can be used on almost any size equipment from fans and blowers to construction and mining machines, where they are used most often.

Hydraulic clutches are mechanical friction clutches actuated with hydraulic oil acting on pistons. The oil is delivered at pressures as high as 500 psi, which accounts for the high torque-transmission capability. In general, operating pressure is a function of torque, speed, cycle rate, and B-10 bearing life.

Operating principles for hydraulically actuated clutches are similar to those for pneumatically actuated clutches. Friction elements can be immersed in oil to cool them, and the piston seals keep out dirt. However, if oil immersion is used, multiple clutch elements must be added to maintain the torque level.

Hydraulic actuation usually provides fast response, and smooth engagement can be produced by controlling the rate of pressure buildup with a pressure-control valve. Because fast response normally is a prime reason for using hydraulically actuated clutches, they require relatively short, large-diameter fluid lines. Remote locations or unusual control requirements may demand additional fluid-control devices to maintain oil pressure at the clutch.

As with pneumatic clutches, the main disadvantage of hydraulic clutches is maintenance of the support equipment (pump, valves, and piping). This equipment generally is more sophisticated than that for pneumatic clutches and requires skilled maintenance personnel. In addition, hydraulic piping is more complicated to install than pneumatic piping, requiring a knowledge of fluid-power principles.

Mechanical brakes

A brake absorbs energy. The energy is converted to heat, so the prime concerns in a brake are: 1. Generating a force capable of retarding a rotating shaft. 2. Dissipating or absorbing the tremendous amount of heat generated in the process.

Mechanical brakes all act by generating frictional forces as two surfaces rub against each other. The stopping power or capacity of a brake depends largely on the surface area of frictional

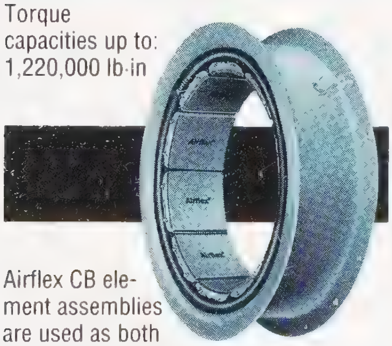
Airflex® Clutches & Brakes

A complete line of clutches and brakes for all types of industrial machinery and equipment.

Constricting Type Clutches and Brakes

Type CB

Torque
capacities up to:
1,220,000 lb·in

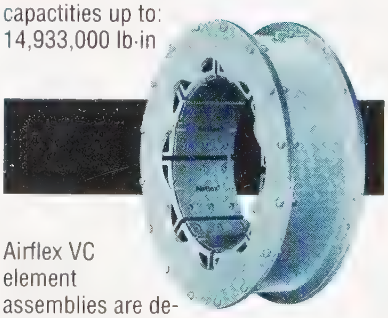


Airflex CB element assemblies are used as both clutches and brakes in general power transmission service. The primary feature of the CB design and construction is the Airflex torsional resilient principle made possible by the transmission of power through the sidewalls of the flexible neoprene and cord actuating tube. This flexibility also permits minor shaft misalignment.

Circle 188

Type VC

Torque
capactities up to:
14,933,000 lb·in



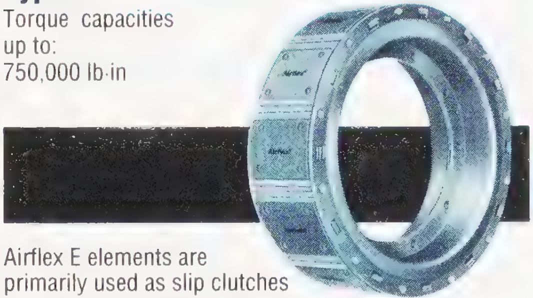
Airflex VC element assemblies are designed and built for severe clutching and braking applications on heavy-duty equipment. They are unmatched for high starting loads and sustained slippage where heat generated tends to lower efficiency and shorten the operating life of conventional clutches. Their high torque ratings permit use of small diameter units which lowers contact velocity on high speed applications. Ventilated construction permits passage of cooling air, to rapidly dissipate heat from the friction shoes. Torque is transmitted from the inside plates of the elements through torque bars to the fiction shoes.

Circle 189

Expanding Type Clutch or Brake

Type E

Torque capacities up to: 750,000 lb·in

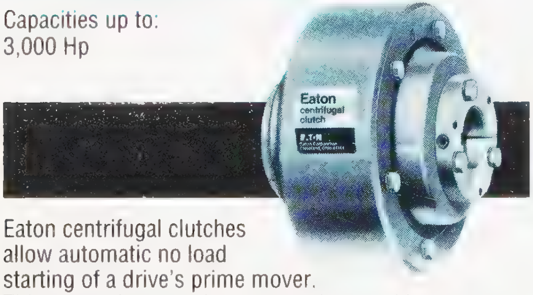


Airflex E elements are primarily used as slip clutches or tension brakes; however, they can also be used for general power transmission service. Torque is transmitted from the friction shoes to the element housing through torque bars. Engagement occurs when air expands the actuating tube forcing the friction shoes against the inside diameter of the drum. Release springs assist shoe disengagement and counteracts centrifugal force.

Circle 190

Centrifugal Clutches

Capacities up to: 3,000 Hp



Eaton centrifugal clutches allow automatic no load starting of a drive's prime mover. This means less starting current draw and lower power cost for an electric motor and a warm-up period for an engine to prevent stalling.

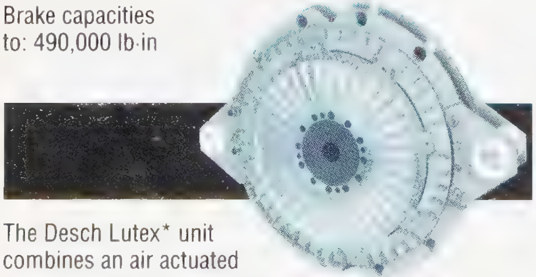
Eaton clutches provide smooth, uniform acceleration regardless of the starting torque characteristics of the prime mover because torque transmitted to the load builds smoothly as a function of speed.

Circle 191

Clutch/Brake Combination

Clutch capacities to: 770,000 lb·in

Brake capacities to: 490,000 lb·in



The Desch Lutex* unit combines an air actuated disc clutch and spring-applied disc brake into a compact package, which can be readily adapted to new or existing flywheel drives. Designed primarily for high cyclic punch press service the unit has been applied on a wide variety of high speed, high cyclic applications.

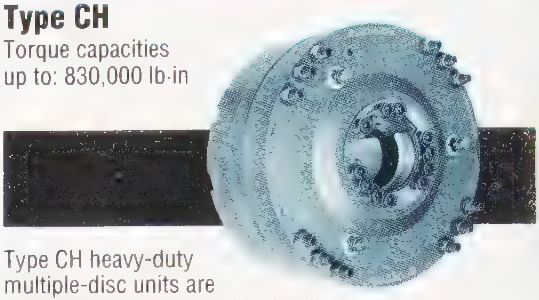
Circle 192

Tade name of Desch Antriebstechnik GmbH & Co. of Arnsberg, Germany

Disc Type Clutch or Brake

Type CH

Torque capacities up to: 830,000 lb·in



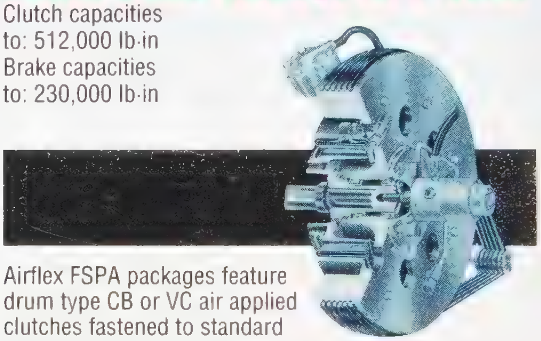
Type CH heavy-duty multiple-disc units are designed for either air of hydraulic actuation. They are suitable for wet or dry operation. When operating in oil, the sintered bronze friction material delivers a low static to dynamic torque ratio for smooth acceleration and high energy performance.

Circle 193

Clutch/Brake Package for Presses

Clutch capacities to: 512,000 lb·in

Brake capacities to: 230,000 lb·in



Airflex FSPA packages feature drum type CB or VC air applied clutches fastened to standard bearing-mounted flywheels. These clutch/flywheel assemblies are then combined with drum type CS and CTE or disc type DBA spring-applied, air released brakes. Although designed primarily for punch press use, they have found application on all types of cyclic equipment.

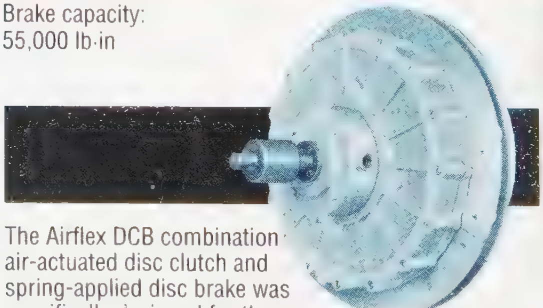
Airflex press controls feature two indenpendent circuits electrically interlocked and monitored to provide two-hand protection.

Circle 194

Type DCB Clutch/Brake Combinatio

Clutch capacity: 75,000 lb·in

Brake capacity: 55,000 lb·in



The Airflex DCB combination air-actuated disc clutch and spring-applied disc brake was specifically designed for the can making industry. It is ideally suited for high speed continuously running machinery requiring an extremely fast stop.

Circle 195

pring-Applied Brake

ype CS

tatic Torque
apacities
p to: 18,000 lb·in

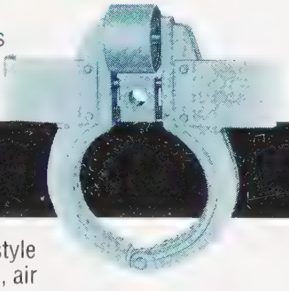
he Airflex CS drum style rake is spring-applied and ir released. It automatically engages should an air or lectrical loss of power occur. The brake is unidirec-ional, developing less torque in the reverse direction of rum rotation.

Circle 196

pring-Applied Brake

ype CTE

tatic torque capacities
p to: 98,500 lb·in



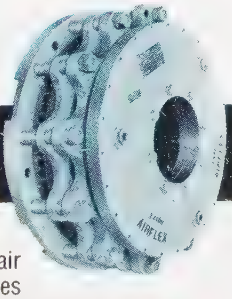
he Airflex CTE drum style rake is spring-applied, air eleased and develops greater torque than Type CS. s design and construction are ideal for moderate peed, high torque, cyclic applications. The brake is idirectional, developing approximately the same orque in either direction of drum rotation.

Circle 197

pring-Applied Brake

ype DB

tatic torque capacities
p to: 420,000 lb·in



he Airflex DBA disc style rake is spring-applied and air eleased. Its torque capacities nd heat dissipation characterisitcs make it ideal for igh speed cyclic applications. Equal torque is eveloped in either direction of rotation. Units are vailable with either ventilated or solid discs.

Circle 198

Caliper Disc Brake

Types DP and H

Frictional force
capacities up to:
5,300 lb

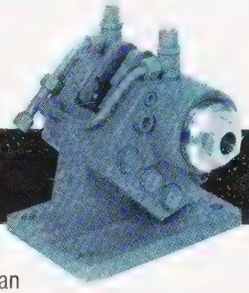
The Airflex design features opposed pistons for balanced braking. Their symmetrical split construction accommodate discs of any thicknesses, and permits mounting from either side of the split line. Type DP is ideally suited for most stopping and light tensioning applications. An automatic adjustment mechanism compensates for lining wear and maintains constant release clearance and response time.

Circle 199

Caliper Disc Brake

Type SKD and SKP

Frictional force capacities
up to: 44,960 lb



The Dellner-Malmco* caliper product line offers an extensive range of brake sizes in either pressure applied or spring-applied designs. They utilize opposed pistons in a two-piece housing. The symmetrical construction permits mounting between the housing halves and allows the use of different disc thicknesses.

**Trade name of AB Dellner-Malmco, Falun, Sweden.*

Circle 200

Water Cooled Brake

Type WC

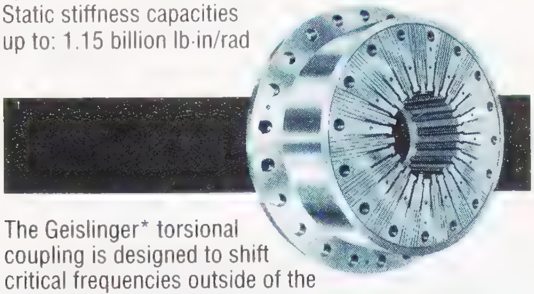
Torque capacities
up to: 1,800,000 lb·in
Thermal capacities
up to: 1,960 HP

Airflex WC air applied water cooled brakes are designed for applications requiring high horse-power absorption. Its design incorporates copper alloy wear plates which transfer heat rapidly to circulating water. They are used for heavy-duty braking and tensioning applications, such as those found in metal and paper processing, as well as for cable tension control on logging, marine mooring and winching equipment. The unit can also be used as an absorption dynamometer.

Circle 201

Torsional Couplings and Dampers

Torque capacities
up to: 57,700,000 lb·in
Static stiffness capacities
up to: 1.15 billion lb·in/rad



The Geislinger* torsional coupling is designed to shift critical frequencies outside of the system operating range and to dampen frequencies remaining in the range.

Used extensively on diesel and internal combustion engine drives, it features a unique design incorporating multiple leaf springs and oil displacement chambers to combine torsional stiffness with damping.

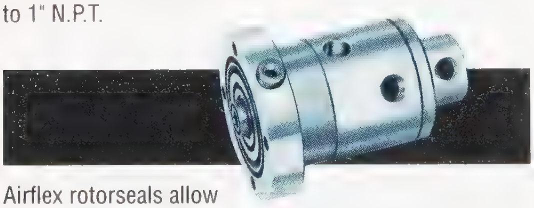
The Geislinger damper is similar in design to the coupling and mounts on the free end of an internal combustion engine crankshaft for damping engine excitations.

Trade name of Dr. Ing. Geislinger & Co.

Circle 202

Rotorseals

Single passage to 2" N.P.T.
Dual or triple passage
to 1" N.P.T.



Airflex rotorseals allow passage of pressurized fluids from a stationary inlet to a rotating shaft end. Single, dual and triple passage rotorseals are available in a variety of sizes and designs to meet most flow requirements. The multiple passage units can be used for individual control of components mounted on the same shaft, component lubrication and circulating fluid systems.

Circle 203

Flexible Link Couplings

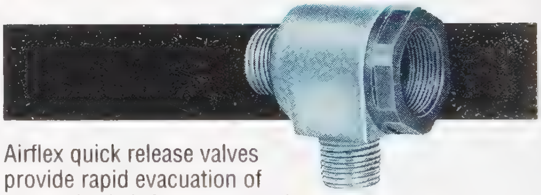
Torque capacities
up to: 24,900,000
Angular misalignment
to: 0.69 degrees

The Geislinger flexible link coupling is designed to compensate for shaft parallel and angular misalignment. It consists of tangential links of spring steel, which connect the driving and driven members of the coupling. This design results in small reaction forces being transmitted to the drive line support bearings.

Circle 204

Quick Release Valves

Up to 1" N.P.T.



Airflex quick release valves provide rapid evacuation of pressurized air from pneumatic devices. They provide an exhaust port at the device rather than at the end of a long supply line and/or control component. Exhaust is rapid and positive as soon as there is a pressure drop in the supply line.

Circle 205

For more information...

Eaton's worldwide network of Sales Engineers and Distributors are ready to assist you with additional technical data or application information. Call the 800 number below for the name of your nearest Airflex sales office or send for this free 464 page catalog. It covers complete engineering information on all Airflex clutches and brakes.

Airflex
Clutches and Brakes
E·T·N

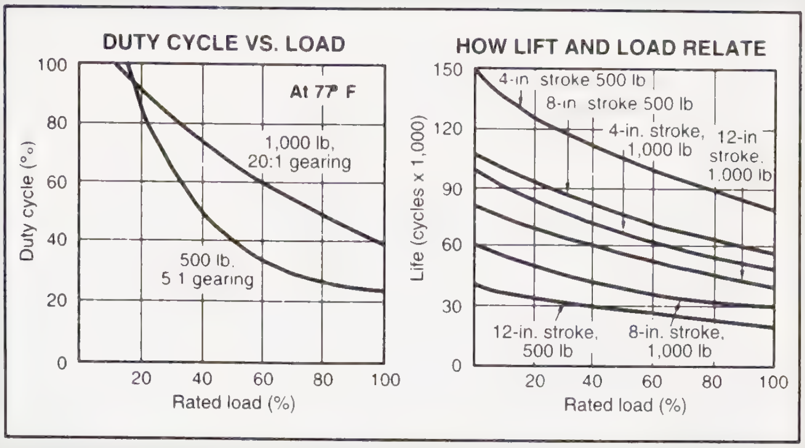
Phone: 1-800-233-5890 (in Ohio 1-800-233-5903)
FAX: 216/281-3890

Eaton Corporation
Airflex Division
9919 Clinton Road
Cleveland, Ohio 44144

E·T·N

ONSIDERATIONS FOR LECTROMECHANICAL ACTUATORS

e trend among equipment builders is to buy more ady-to-use systems for their machines. Elec- omechanical actuators or electric cylinders are one ample of small systems that are easily incorpo- ted into machine designs to provide action for its embers.



EM-linear actuators are self-contained lead- ews driven by an electric motor usually through a ar reducer to increase torque. The motors may be or dc and the leadscrew may use an Acme or ll-bearing design. Acme screws operate with the ding motion of a nut and bolt and have 30 to 45% iciency. The more-costly ball screws have about % efficiency. For a comparable size and current aw, ball-screw units can move twice the load of an me screw, or the same load twice as fast. Con- rsely, for the same load and speed, ball-screw ac- ators draw half the current of those with Acme screws.

However, the relative inefficiency of Acme screws can be a nefit because they can hold loads in position or prevent back- iving when power is removed, even in most vertical installa- ns. Ball-screw actuators, on the other hand, usually require a ad-holding brake to prevent backdriving when power is off. hen loads must be held, a bidirectional no-back wrap-spring ake works well. On ball-screw linear actuators, electrically eased spring brakes are often used to hold loads when electri- power is off.

Major selection factors for the actuators include load, voltage, d stroke. However, some applications require attention to her details such as life expectancy, duty cycle, precision and peatability, and cost.

The magnitude and direction of dynamic loads are critical ctors in selecting a linear actuator. In horizontal applications, ad direction typically opposes actuator movement. Actuators ually extend against compressive load and retract against nsion loads. In vertical applications, on the other hand, the ad is often in one direction, either all compression or all ten- n. With unidirectional loads, a ball-screw holding brake may quire special design considerations. A no-back wrap-spring ake provides maximum life when loads oppose the travel direc- n. With unidirection loads, brake life depends on stroke, eed, length, and dynamic load.

With bidirectional loads, the axial end play of the actuator fects its position when loads change direction. Preloaded ball ews and thrust assemblies, or antibacklash gears may mini- ze end play. But these devices may be unnecessary if the final proach to a target position is always from the same direction, en when travel involves overshooting and backtracking.

A safety factor for dynamic loading may be increased for applications such as ensuring operator safety. The higher load rating, beyond application requirement, can increase actuator performance or life.

Static loads often equal dynamic loads but, in some applications, they may be much higher. For instance, an actuator may move a lift table to a position where it stops and an additional load is applied or transported across it. In these cases, actuator holding capacity limitations must be understood to ensure an adequate safety margin.

Life of a linear actuator depends on load and stroke length, as illustrated in the duty cycle versus load curves. As stroke lengthens and dynamic or static compression loads get higher, column loading increases. Excessive column loading can cause bucking of the leadscrew or extension tube. Critical column- buckling load, P_{crit} is

$$P_{crit} = 14.05(10^6)CD^4/L^2$$

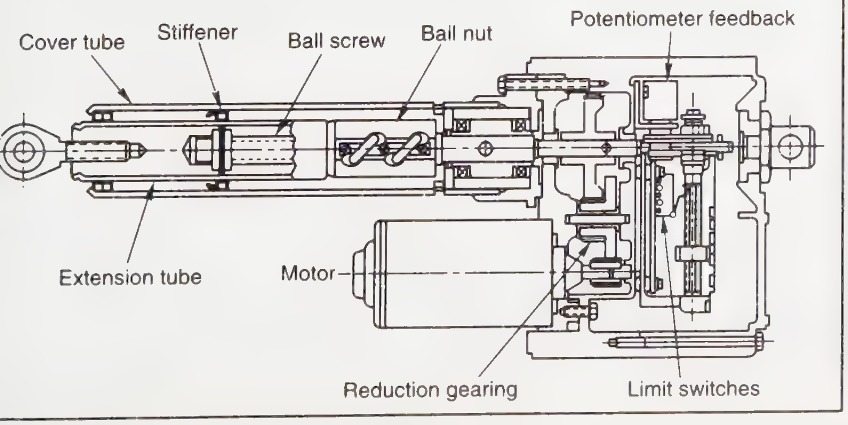
where D = screw minor diameter, in.; L = unsupported leadscrew length, in.; and C = end-fixture factor. C ranges from 0.25 to 4.0, depending on the support bearing system, but most modern actuators range from 1 to 2.

To increase column loading capability of longer stroke actuators, designers must increase the leadscrew diameter and wall thickness of the extension tube, and add a stiffener between the extension tube and out tube to prevent buckling. The stiffener is located where the extension tube is most susceptible to bending when fully extended. For safety, extension tubes also handle load. Usually it is a percent of the rated load, and often about 20%. Intentional side loading is not recommended because it reduces leadscrew life.

Linear actuators are designed to operate with loads in line with their axes, avoiding side loading. If loads are off center, screw and nut life will be reduced, leading to premature failure. Effects of side loads are difficult to predict and evaluate beforehand because they may vary throughout the length of stroke for each application. When side loads are unavoidable, life tests should be performed for the application.

Linear actuators frequently move through an arc, in operations such as opening a door. It is imperative that the unit's mounting pins are parallel to allow freedom of motion in two degrees, keeping the load squarely on the actuator's axis. Where more degrees of freedom are required, most manufacturers recommend spherical rod ends to transfer load more axially to the actuator.

INSIDE AN ELECTRO-MECHANICAL ACTUATOR



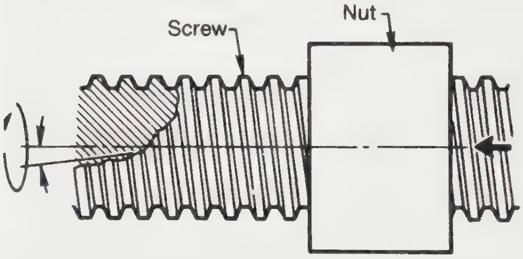
surfaces as well as on the actuation force applied. The friction and wear encountered by the working surfaces are severe, and the durability of a brake (or service life between maintenance) depends heavily on the type of material used to line the shoe or pad, which generally is the "wearing" or replaceable surface in a brake. The drum or disc is designed to undergo minimum wear and is a permanent part of the brake.

Brake linings

Most brakes use some type of friction lining. Asbestos, once the accepted friction material, has been replaced in many cases by nonasbestos materials. Contents of the new material, largely proprietary, are also fibers molded or woven into pads or discs. Copper is sometimes added to improve heat dissipation. Cotton-based linings are sometimes used for light-duty service.

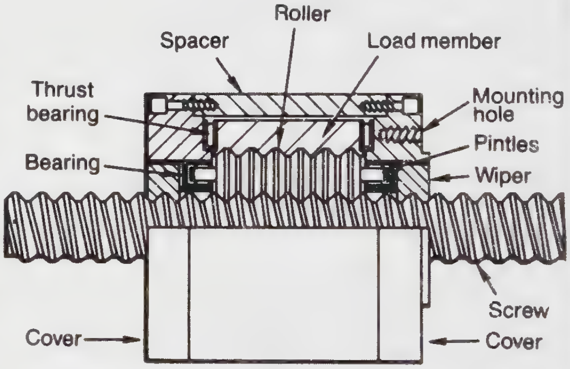
LINEAR ACTUATORS

Planetary roller screws have rollers positioned between the nut and screw shaft. These threaded rollers, in most cases, travel only in a planetary path around the shaft and do not advance axially when the shaft or nut is rotated. Consequently, rollers do not have to be recirculated. Each roller end terminates in a spigot that mates with a guide ring that prevents rollers from sliding with respect to the nut. Also, the guide rings hold rollers equally spaced around the shaft and prevent contact between adjacent rollers. Rollers are positively driven by teeth on the end rings which mesh with teeth at the roller ends. Locating pins tie the end rings and nut together. Retaining rings hold the guide rings in position. Most commonly, the lead of planetary roller screws is 5 mm (or 5 turns/in.) or coarser. The advantages of planetary roller screws are high load capacity and high linear speed.



Power screws consist of a nut running on a rotating screw. Contact is primarily sliding, resulting in relatively low efficiency and a wear rate proportional to usage. The screw thread can be any form including ACME, square, buttress, Whitworth, or unified. Advantages of power screws include self-locking capability in the back-drive mode, low initial costs, ease of manufacture, and wide choice of materials. Disadvantages include lower efficiencies compared to ball screws and difficulty in predicting service life.

Recirculating roller screws use rollers between the screw shaft and nut. For each rotation around the screw, the rollers advance axially a travel equal to the start of the nut. The nut has an axial groove (machined in-line with cams) that relieves each roller of load at the completion of each revolution. When a roller reaches the groove, it is displaced radially and taken out of contact with the shaft. As the nut continues to turn, cams recirculate the unloaded roller back to its original position. A cage guides roller movement. Advantages of the recirculating roller screw are high load capacity and thread lead as small as 0.8 mm.

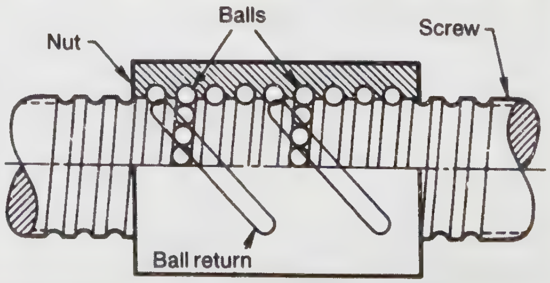


Spiracon is a proprietary design. It consists of a screw engaged by rollers which have annular rings and grooves conjugate to the threads of the screw, thus producing full line contact. The rollers also mesh with the load member, which also has annular rings and grooves. Load member is free to rotate within the assembly and is held concentric by the symmetrical distribution of the rollers which engage it. Load member is located axially between thrust bearings, which transfer the axial forces to the housing assembly.

Rollers are in equilibrium between the screw and load member and need no other support except for the relatively small tangential forces resulting from the input driving torque; thus, the covers engage the roller pintles through the pintle bearings to prevent their planetary motion.

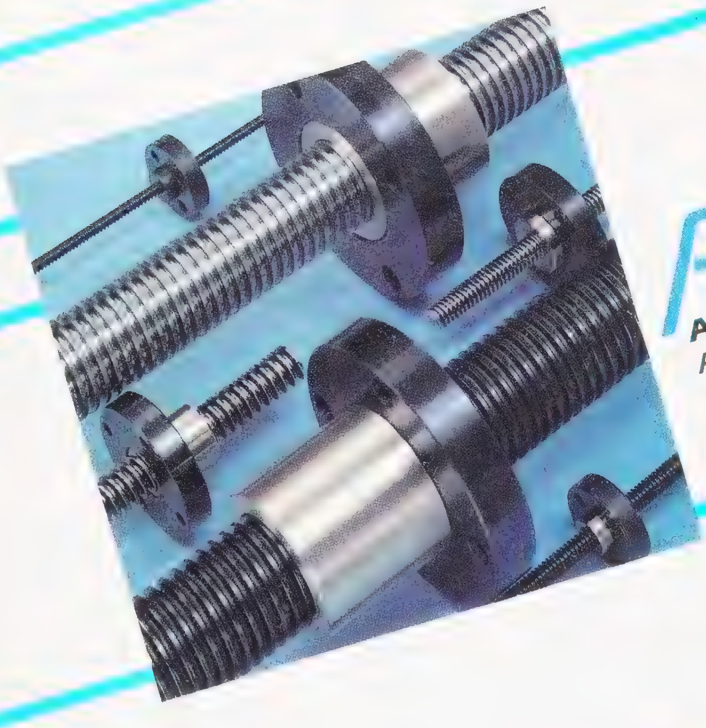
Large axial forces are transmitted through rolling contact from the screw to the load member via the rollers and ultimately to the housing assembly.

Ball screws are essentially power screws with a train of ball bearings riding between the screw and nut in a recirculating track. The larger number of mating parts — compared to power screws — makes fit-up tolerances more critical. The screw has a rounded shape to conform to the balls. Greatest advantage ball screws is their high efficiency. However, because it cannot self-lock, a ball screw requires an auxiliary brake to prevent back driving. Further advantages of ball screws are predictable service life and low-wear rate. Disadvantages include limited material choice and higher cost relative to power screws.



Take a look at
NOOK
The Linear Motion People

NOOK INDUSTRIES



Power•ac™

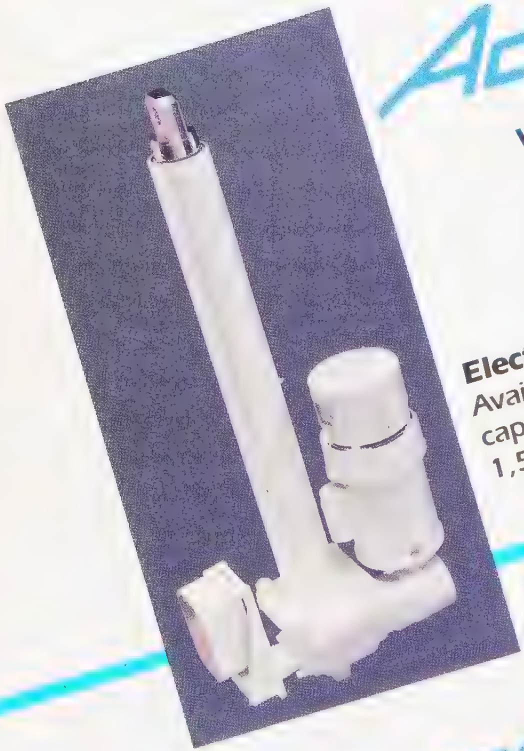
Acme Screws and Nuts
Available in 42 standard screw sizes ranging from $^1/_4$" to $4^1/_2$"

Actionjac®

Worm Gear Screw Jacs
Ball screw or Machine screw jacs with load capacities from 500 pounds to 50 tons

New Metric Sizes

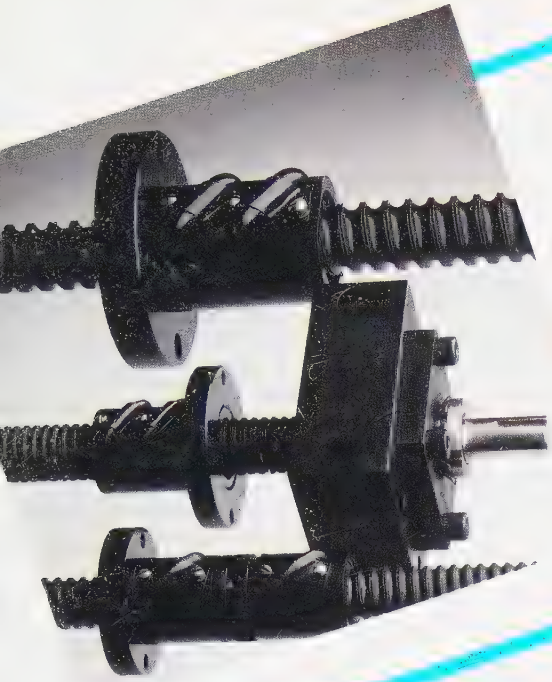
Electric Cylinder Jacs
Available in load capacities ranging from 1,500 to 40,000 pounds



Power•Trax™

Ball Splines
Stock precision ball splines available from $^3/_8$" to 4" diameter

Shafting
Stock precision case hardened and ground shafting available from $^1/_2$" to 3" diameter



PowerTrac®

Rolled Thread and Ground Thread Ball Screws
Available machined to
your specifications in
18 standard screw sizes
ranging from $^3/_8$" to 4"

Precision Slides
Low friction,
low backlash slides
offer accurate positioning
at high speeds.

Power Cylinders
Cylinders offer
integral limit switches,
overload safety devices
and a broad range
of speeds.
Load capacity from
500 pounds to 20 tons.

For over twenty years Nook Industries, Cleveland, Ohio . . . has been a major source of linear power transmission components. Our family of products is constantly growing to meet the needs of today's industry.

MADE IN USA

ROLLED-THREAD BALL SCREWS

Forty-page Design Guide helps readers quickly and accurately select correct Power*Trac ball screw and nut for particular application. Simplified charts describe life expectancy, column strength, and critical speed Mounting blocks are also included. **Nook Industries Inc.,** 23200 Commerce Park Rd., Cleveland, OH 44122. Phone (800) 321-7800 for engineer hotline or (216) 464-4393.

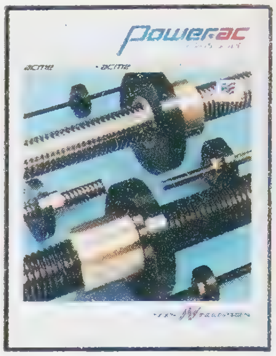
New precision rolled ball screws available.

Circle 206

ACME-THREAD SCREWS AND NUTS

Power*Ac Design Guide provides complete information for use in the proper selection and application of acme-thread screws, the companion nuts, and mounting flanges manufactured by Nook Industries. Engineering design data are also presented. **Nook Industries Inc.,** 23200 Commerce Park Rd., Cleveland, OH 44122.
Phone (800) 321-7800 for engineer hotline or (216) 464-4393.

Circle 210



LINEAR BALL BEARING

The new PowerTrax™ Linear Ball Bearing Design Guide lists sizes available from 1/8" to 4" in Precision, Extra-Precision, Commercial, Adjustable, Open, Pillow Block and Instrument configurations. These bearings have high speed and high load capacities. **Nook Industries, Inc.,** 23200 Commerce Park Rd., Cleveland, OH 44122.
Phone (800) 321-7800 for engineering hotline or (216) 464-4393

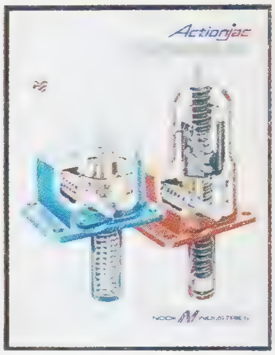
Circle 207

WORM GEAR SCREW JACKS

ActionJac Design Guide simplifies selection and use of standard machine screw and ball screw jack systems with capacities from 1/4-50 tons. Simplified charts are used to easily solve complicated calculations in selection process. **Nook Industries Inc.,** 23200 Commerce Park Rd., Cleveland, OH 44122.
Phone (800) 321-7800 for engineer hotline or (216) 464-4393.

New metric sizes available.

Circle 211



POWER CYLINDERS

The new ActionJac™ Power Cylinder Design Guide provides complete information on the wide range of sizes, integral limit switches, overload safety devices and broad range of speeds available. Load capacities are from 500 pounds to 20 tons. **Nook Industries, Inc.,** 23200 Commerce Park Rd., Cleveland, OH 44122,
Phone (800) 321-7800 for engineering hotline or (216) 464-4393

Circle 208

BALL SCREW BEARING MOUNTS

Power*Trac EZZE-MOUNTS have two mounting surfaces, are compact-designed and allow for easy installation. An exploded view of the EZZE-MOUNT, top and side views of the two available styles and supporting charts assist engineers when ordering. **Nook Industries Inc.,** 23200 Commerce Park Rd., Cleveland, OH 44122.
Phone (800) 321-7800 for engineer hotline or (216) 464-4393.

Circle 212

PRECISION POSITIONING SLIDE

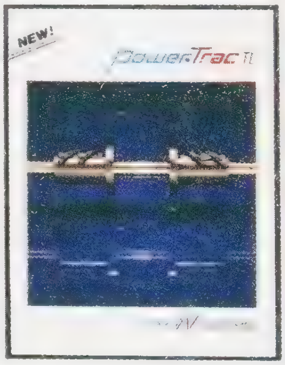
Power*Trax cost-effective precision slides offer accurate positioning of heavy loads at high speeds. Brochure includes technical charts and drawings for slides and standard motor mountings. **Nook Industries Inc.,** 23200 Commerce Park Rd., Cleveland, OH 44122.
Phone (800) 321-7800 for engineer hotline or (216) 464-4393.

Circle 209

TWIN-LEAD BALL SCREWS

Power*Trac twin-lead ball screws are a cost-efficient method to perform dual-opposing linear motion using one drive system. Design applications include: molding, packaging, robotics and assembly applications. Ordering information is provided along with the chart and diagram. **Nook Industries Inc.,** 23200 Commerce Park Rd., Cleveland, OH 44122. Phone (800) 321-7800 for engineer hotline or (216) 464-4393.

Circle 213



NOOK INDUSTRIES
THE LINEAR MOTION PEOPLE

MADE IN USA

23200 Commerce Park Road
Cleveland, Ohio 44122-5869
(216) 464-4393 FAX: (216) 464-4669
TOLL FREE: 1-800-321-7800

CABLE CARRIERS PROTECT CONTROL WIRING

Cable carriers are hollow tracks that support and protect wiring and interconnections on moving machine elements such as machining centers, washing gantries, and injection-molding robots. The protectors are available in designs:

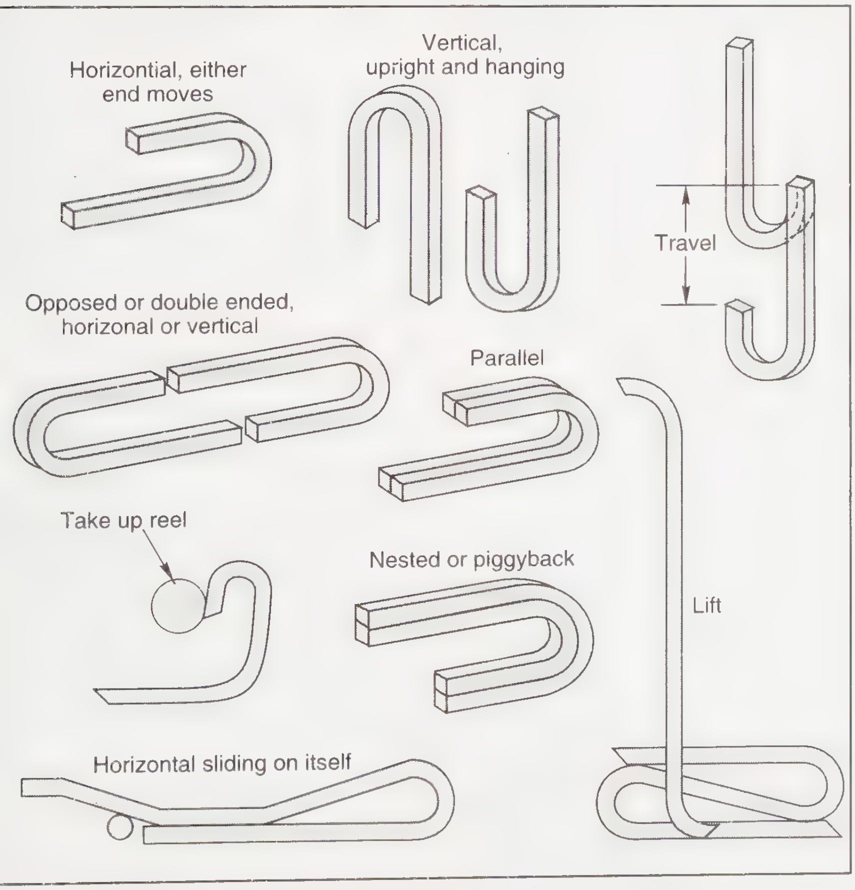
Metal-link units consist of parallel sidelinks jointed by crossbars that form a cavity to accommodate cables. Pivot pins and stops allow links to travel through predetermined arcs of as much as 45°. Restricted-link travel is a convenient option because it often limits the carrier's bending radius and prevents sagging. Metal-link carriers work best in slow-moving, heavy equipment such as machine tools.

Enclosed-metal carriers are made of flexible tubing with small convolutions and provide better protection than open-link carriers. Fully enclosing cables protects them from debris such as sparks and hot-metal chips. Unlike metal-link carriers, enclosed-metal carriers are not limited with constrained travel arcs. Thus, they operate at higher speeds. Enclosed-metal carriers work well on robots and can be electrically grounded to provide EMI/RFI shielding. However, manufacturers recommend that grounded carriers serve only as redundant isolation for shielded signal wires.

Closed-metal units also withstand rough handling, such as being kicked, banged, and stepped on. But if the metal takes a dent, it can hinder carrier motion. Plastic carriers may not be as strong as metal, but often are more resilient.

Plastic-link carriers endure speeds similar to tubular metal designs, but plastic units are lighter, wider, and have more carrying capacity. Although they leave cables exposed for easy inspection, they do not defend against debris.

Plastic-tubes are enclosed carriers that weigh less than metal-tube versions, giving them an edge in width and speed. They also offer protection from outside elements not available in plastic-link carriers. High-speed applications that require corrosion resistance, such as a car wash or a machine with heavy coolant spray, are likely candidates for plastic-tube carriers.


Horizontial, either end moves
Vertical, upright and hanging
Travel
Opposed or double ended, horizonal or vertical
Parallel
Take up reel
Nested or piggyback
Lift
Horizontal sliding on itself

For heavy-duty service, sintered metal linings perform better than asbestos-based linings. Cermet linings are used for extremely rigorous service.

Linings are attached to the brake shoe either by riveting or bonding. Riveted attachment is simpler, but usable lining depth depends upon the depth of rivet-head countersink. Also, rivet heads may score the drum if the linings are not replaced soon enough.

Electric brakes

Electric brakes operate according to the same principles as electric clutches. The most commonly used electric brakes are electrically actuated but rely on mechanical friction for stopping action. Such brakes are virtually the only electrical types suitable when the load must be brought to a full stop. The other electrical types — magnetic-particle, hysteresis, and eddy-current brakes — are primarily used to provide drag or retarding action where a rapid or precise full stop is not needed.

Universal joints

Universal joints, or U-joints, are used to join shafts that must intersect at angles greater than those that can be accommodated by flexible couplings. They are generally classified by their motion transmission characteristic, which can be either constant velocity, nonconstant velocity, or near-constant velocity. U-joints can also be classified by their application: automotive, industrial, or mechanism.

U-joints by application

U-joints fall into three categories:

Automotive U-joints: Used for wheel drive shafts on cars, trucks, and off-highway vehicles, such as tractors, and earth-moving equipment.

Industrial U-joints: Used on vertical pumps, test stands, main rolling-mill drives and auxiliary equipment. Available in sizes to 40 in. in diameter and capable of 15° misalignment, with torques to 15 million lb-in.

Mechanism U-joints: Used for cranking, steering, and others. Available from fractional to several hundred horsepower. Misalignments, 40° on a single unit and 80° on double units.

Springs

Most mechanical-drive systems use springs and springlike parts, such as retaining clips and spring washers. Although relatively small and inexpensive, these components are often critical to the reliable performance of a drive system.

Hooke's Law, which states that deflection is proportional to load, is still the basis for spring design. However, the technology to measure and predict stress, improved spring materials, and the predictability of performance springs has grown significantly.

Typically, springs are classified by four general functions:

Pushing is done by compression springs, spring washers, volute, and beam springs. Helical compression spring are most common for large deflections. Spring washers are most common for small deflections. Volute springs have high damping capacity and good resistance to bucking, but are not common because of their relatively high manufacturing cost.

Pulling is done by extension springs, drawbar spring assemblies, and constant-force springs. Helical extension springs are most common. Drawbar spring assemblies are useful when a fixed stop is required. Constant-force springs are similar to power springs except they are loaded by pull rather than twist.

Retaining rings and garter springs push or pull. They retain or locate parts in bearings and on shafts. Garter springs are used primarily in oil seals.

Beam springs are produced in a variety of shapes and can push or pull. Frequently, beam springs are required for additional functions and sometimes are integral to a larger part.

Twisting or torsion is done by helical-torsion and spiral springs. Helical-torsion springs are often used as a counterbalance or for mechanisms that rotate on a shaft. Spiral hair springs

SPRING DESIGN GUIDELINES

When designing a spring or selecting one from stock, manufacturers recommend these guidelines:

1. Define the spring function, space limitations, environment, service requirements, and special considerations. Function is usually expressed as load at test position or spring rate or both. Space limitations are the envelope in which the spring works. Environment is the operating temperature and substance contacting the spring. Service requirements include expected life, frequency, loading rate, and permissible relaxation. Special considerations may include restrictions due to assembly, electrical conductivity or magnetic requirements.
2. Select a configuration for the function. To do this, define the primary spring function in terms of push, pull, twist, or energy storage. Then, review alternative configurations and select one or two best candidates. Finally, compare candidate configuration with respect to cost and special considerations. The final candidates should also meet space requirements most economically.
3. Select a spring material. Carbon spring steel is suitable for most applications unless there are electrical, corrosion, magnetic, or special performance considerations. One convenient method for making rough comparisons of various spring material is to consider energy storage capacity per unit cost.
4. Select a stress level that gives a satisfactory balance between cost and reliability. Because performance is stress related, this is an important step.
5. Consider other restrictions imposed by design criteria. Cost is often a primary restriction. Although specifics on cost cannot be addressed until a spring is designed, there are some guidelines. For sample and small quantities, stock precision-engineered components are available from manufacturers at lower cost than custom-designed springs. For many applications it is possible to use standard spring designs which save engineering time, avoid tooling costs, and special manufacturing lot charges.

Custom-designed wire springs are generally less costly than strip springs because there is very little scrap from wire. Many flat springs are blanked from strip, and hence involve scrap. Springs made from prehardened material tend to be less costly than springs hardened after forming. Sharp bends tend to increase manufacturing costs and cause stress concentrations that result in early failure.

Compression springs and several other types of common springs are made on universal tooling. Most flat spring and special wire forms require special tooling. The ability to maintain tolerances varies considerably for different spring configurations. Generally, tolerances controlled by metal-forming processes are greater than tolerances controlled by metal cutting.

Energy storage capacity (ESC) for different configurations

Spring type	Energy storage capacity	Space efficiency	Typical amounts of energy stored in spring space envelope (ft-lb/in^3)
Compression or extension			
Round wire	$\frac{S^2}{4G}$	$\frac{\pi D/d}{(D/d + 1)^2}$	1.8 to 18
Square wire	$\frac{S^2}{6.5G}$	$\frac{4D/d}{(D/d + 1)^2}$	1.2 to 12
		(Space efficiency does not apply to extension springs)	
Rectangular cantilever and simply supported beam	$\frac{S^2}{18E}$	—	—
Cantilever beam of triangular wire	$\frac{S^2}{6E}$	—	—
Helical torsion springs			
Round wire	$\frac{S^2}{8E}$	$\frac{D/d}{(D/d + 1)^2}$	1.2 to 6
Square wire	$\frac{S^2}{6E}$	$\frac{4D/d}{(D/d + 1)^2}$	1.8 to 9.7
Spiral torsion of round wire	$\frac{S^2}{8E}$	—	—
Belleville washer (OD/ID ratio of 2 is preferred for most designs)	$\frac{S^2}{10E}$ to $\frac{S^2}{40E}$	0.6 to 0.9	0.6 to 6
Power spring	—	0.4 to 0.6	12 to 20
Prestressed power spring	—	0.4 to 0.6	30 to 35
Typical lead acid battery	—	—	3,000 to 4,000

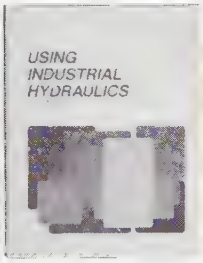
$ESC = \frac{1}{V}\int_0^f kf\,df$, where V = volume of active spring material, in^3. Also from the table, S = maximum stress, psi; g = shear modulus of rigidity, psi; D = (ID+OD)/2, in.; d = wire diameter, in.; Copyright, 1987, Barnes Group Inc.

AIR LOGIC
by Hydraulics & Pneumatics Magazine

Item 2152

Written for engineers, designers, students and anyone who must know how pneumatic industrial control systems operate. The book shows how to design simple and complex circuits for industrial applications and explains how air logic hardware operates. Technical information in this text is generic and applies to the hardware available from all manufacturers.

Ralph Culbertson . . . .
164 pages . . hardbound . . **$32.50**



Also Available

Using Industrial Hydraulics Item 2161

Beginning with a thorough introduction to hydraulic principles, this book leads the reader through the complete spectrum of hydraulic components . . . including proportional valves . . . and shows how they're used in fluid power systems. The book was written to bring the fluid power engineer and technician up to the leading edge of technology in component and system design application. Printed in full color — and color keyed — to clearly illustrate component operation and system functions.

T.C. Frankenfield . . . .
400 pages . . . . hardbound . . . **$48.50**

Order toll-free 800-321-7003
(in Ohio 216/696-7000)
Or send your order to:
Penton Education Division
1100 Superior Avenue
Cleveland, Ohio 44114

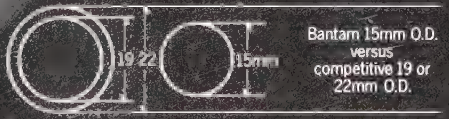
NEW 6x15mm GAS SPRING FROM AVM

BREAKS THROUGH DESIGN BARRIERS

Packs performance and longer life in about half the space. The new Bantam-SX3 gas spring. Sleek. Powerful. Fits where others now can't. Works when others quit. Bantam measures only 15mm. Uses about half the cartridge space others need. And through superior triple-seal technology, Bantam achieves longer life. Even with a powerful P1 of 100 lbs. maximum, 15 lbs. minimum. See this small wonder firsthand.

Call AVM at 1-800-232-4AVM for a free sample*, a quotation you'll like, and the kind of quick turnaround you'd expect.

*Sample free with purchase, call for details.



AVM, INC.
AN ARVIN COMPANY

Highway 76, East Box 729
Marion, South Carolina 29571
1-803-464-7823
1-800-232-4286

AVM GAS SPRINGS
BANTAM
Small Wonder
SX3

© AVM, Inc., 1991

Circle 214

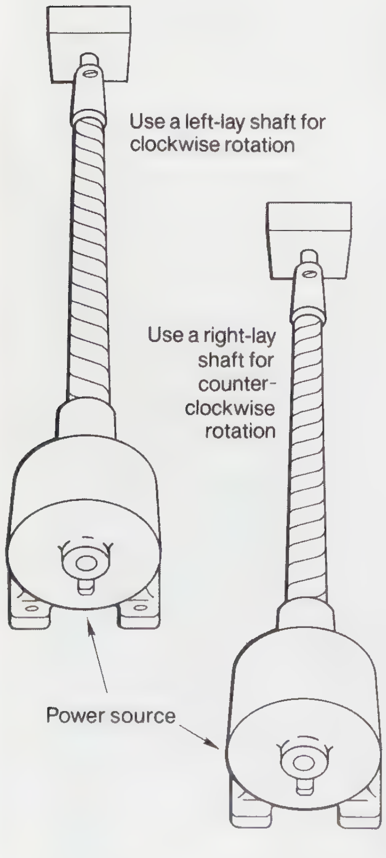
have a low hysteresis and are used in instruments and watches. Brush springs hold brushes against commutators in electric motors; they push or twist. Power springs are often called clock or motor springs and are used to store energy in devices such as timers, clocks, and spring motors for toys and cameras. Prestressed power springs are a special type that twist and have a high energy-storage capacity. They are most commonly used on retractors, such as on seat belts.

Energy-storage capacity or ESC is required for all springs. It is the amount of work done by a spring or the energy stored, per unit volume of active spring material. The table, *Energy-storage capacities of various spring configurations* lists specific ESCs.

Space efficiency is another measure of spring efficiency. It is the volume of active spring material divided by the space envelope of the spring at maximum deflection. Space efficiencies shown in the table are approximate, and refer to springs in fully deflected positions without regard to inactive

FLEXIBLE SHAFTS FOR CONTROL AND POWER

Using more wires in a remote-control shaft increases shaft stiffness and reduces deflection (lag) between the two ends. However, the increased number of wires generates higher internal friction when the shaft is turned — especially when it is curved appreciably. This is why remote-control shafts are suitable for only low-speed or intermittent operation. Since power-transmission shafts have relatively fewer wires, they are more sensitive to unwinding and, therefore, are not intended for rotation "against the grain" of the windings. Remote-control shafts may be rotated in either direction. In contrast, power-transmission types should rotate only in the direction that tends to tighten the last layer of wires. Direction of rotation is determined from the power-source end of the shaft.


Use a left-lay shaft for clockwise rotation
Use a right-lay shaft for counter-clockwise rotation
Power source

FLEXIBLE SHAFTS

One of the simplest methods of transmitting rotary motion between two points on a machine is through flexible shafting. It is especially suited for transmitting power over, under, around, and through obstacles that rule out the use of rigid straight shafts. Flexible shafts are available in many combinations of materials and construction techniques to handle power-transmission requirements up to 7¼ hp and speeds from 0 to 20,000 rpm.

The crucial element of a flexible shaft is the core or basic working element. Core construction varies according to application requirements (torque, bends or angles, torsional deflection, service conditions, and length). The basic core construction is built upon a single wire on which one or more wire layers (of 2 or 3 wires each) are wound. Layers are wound in opposite directions. In most shafts, successive layers use larger size wires and more wires per layer.

Flexible shafts should rotate in the direction that tends to tighten the last layer on the core shaft. Torque capacity of a power drive shaft operated in the unwinding direction is about 60% of that in the tightening direction. Remote-control shafts, on the other hand, are built to operate in both directions, so torque capacity is not affected.

Three types of cores are used: set wire, live wire, and nonravel. Set-wire shafting is the most widely known because of its use in automotive speedometer cables. During manufacture, set-wire shafts are automatically wound back and forth on themselves, with wire size increasing in successive layers. After winding, the shaft is heat treated to set the wire.

Live-wire core is the oldest type made; it is designed for low speeds and high torque. All the wires used in its construction are much finer than wires used in other types, necessitating many more layers to produce comparable sizes. In addition, more wires are used in each layer, resulting in a much stiffer shaft. The high wire concentration permits this core to transmit almost as much torque in the unwinding direction as in the winding direction. This type of core must be soldered or brazed before cutting to length to prevent unwinding.

Nonravel shafting has an assembled core. Music wire is wound onto a mandrel, the mandrel is withdrawn, and the lower layers are pushed into the last layer. When the shaft is released, the coils decrease in size, tightening the assembly.

The latest type of nonravel core combines live-wire and nonravel techniques. In the first two or three layers, live wire is wound and held from expanding. Then, a number of nonravel layers are applied, and the ends are cut off, releasing the inside layers to expand. The nonravel layers then decrease in size to lock the layers together and place the entire shaft under tension.

The casing acts as a support and a bearing for the core and protects the core from moisture, dust, and abrasion. The casing also retains any lubricant surrounding the core. Most casings contain one or more wire braids to resist stretch and twist. Occasionally, flat steel wire or A and D wire is used as an inner liner and is covered with a braid for additional strength.

Two-braid casings provide heavier wall thicknesses for greater stretch and twist resistance in high-torque applications. For heavy-duty applications, three-braid casing provides even greater wall thickness to ensure long life and wear resistance. Asbestos-packed, galvanized and interlocked metal-hose casings are available for severe dust and dirt conditions. To protect the casing in severe environments, a neoprene or plastic cover is placed over the shaft.

Hiwin
Ballscrews

ain higher quality at reduced costs with Hiwin
ecision ballscrews. Also available at an attrac-
e price are replacement kits for upgrading your
dgeport milling machines.
For complete details, contact Carlyle Johnson,
e problem solvers in motion control.

THE CARLYLE JOHNSON MACHINE COMPANY
(203) 643-1531 Fax: (203) 643-0982

Circle 215

Carlyle Johnson
Clutches & Brakes

Don't compromise; get the Maxitorq solution for your motion control problems. Select from our broad line of multiple disc clutches, single plate clutches and brakes or spring-set brakes.

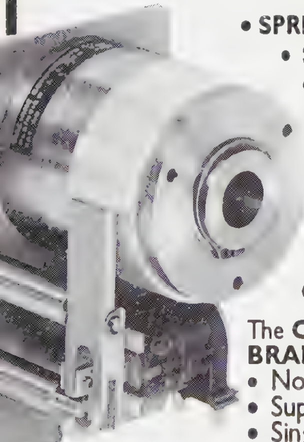
For complete details, contact Carlyle Johnson, the problem solvers in motion control.

THE CARLYLE JOHNSON MACHINE COMPANY
(203) 643-1531 Fax: (203) 643-0982

Circle 216

CLUTCH BRAKES
CNR SERIES PLUS

- SPRING WRAPPED DESIGN
- SOLENOID OPERATED
- NON REVERSING
- FREE FROM RADIAL LOADS
- TORQUES: 50 TO 500 LB.-IN.
- ACCURATE STARTING & STOPPING OF LOADS



The **CNR** series **CLUTCH BRAKES** feature:

- No radial loads on clutch input
- Superior Spring technology
- Single or multiple indexing steps per revolution.
- Indexing accuracy ± 1°
- Errors non-cumulative
- Output cannot be back driven
- Unidirectional rotation
- Clamp coupling to output shaft. Keyways not necessary
- External phasing capability.
- Load lock when solenoid is off
- Solenoid voltages 12, 24 VDC; 110 VAC, 60HZ.

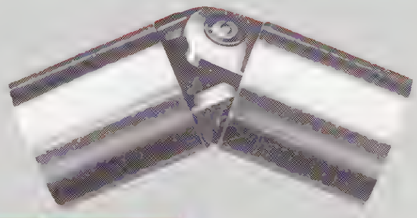
Send for catalog 18D

OUR ENGINEERS WILL MODIFY DESIGNS TO MEET YOUR SPECIFIC REQUIREMENTS

MACHINE COMPONENTS CORPORATION
70 NEWTOWN ROAD
PLAINVIEW, NY 11803 • 516 694-7222 FAX. 516 694-7252

Circle 217

READILY MODIFIED
TO YOUR SPECIFICATIONS



GRAY & PRIOR

ATLAS
UNIVERSAL
JOINTS

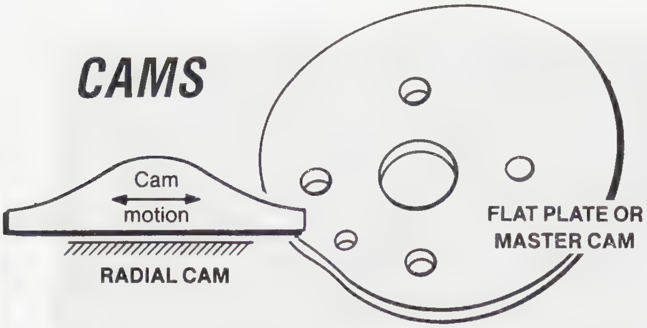
Ends fitted to your specifications: bored, broached, tapped, splined, threaded, etc., with keyways as required. Std. singles and doubles, also hinged gears and heavy duty models. Standards in 14 sizes made from heat treated alloy steel. Bronze and special metals also available. Maximum strength at high speeds with minimum vibration. Take-apart feature. Special lubrication. Low cost.

For Engineering Service, Call
(203) 243-8381

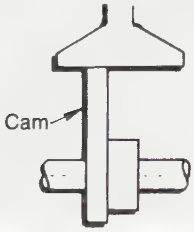
THE
GRAY & PRIOR MACHINE COMPANY
96 Granby St. Bloomfield, Ct. 06002

Circle 218

CAMS

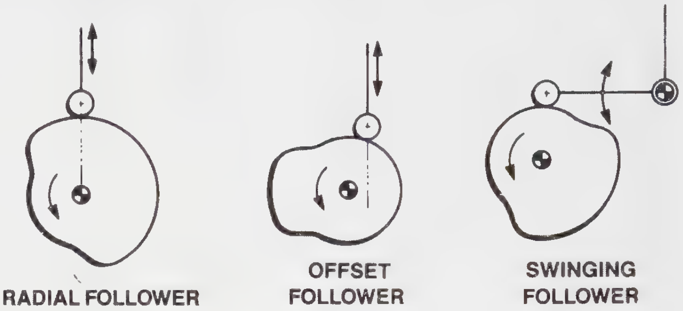


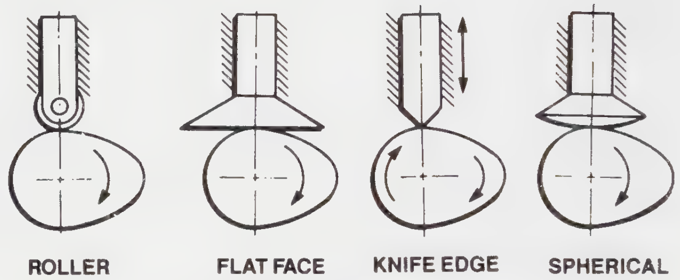
A cam is a device in which the distance from the cam surface to some reference point or surface serves as a control or actuation signal. Cams are used to trigger on-off responses in machines or to position a device in response to the motion of another device. The most common type of cam is the flat-plate cam which, as the name implies, is a contour cut from flat stock. A radial cam uses rotary motion as an input; a translating cam uses straight-line motion as an input. The "signal" or position of the cam surface is read off the cam by a device called a cam follower.



Offsetting a flat-face follower with respect to the cam induces frictional forces that make the follower rotate. Thus, wear is distributed over the follower.

Cam followers can be constrained to respond with straight-line motion aligned through the cam center of rotation (radial follower), straight-line motion aligned off the center of rotation (offset follower), or by rotation about a swinging follower arm (swinging follower). The swinging follower minimizes the pressure between cam and follower and, thus, is often preferred with same cam radii.





YOURS FREE

Screw jack/ actuator engineering guide

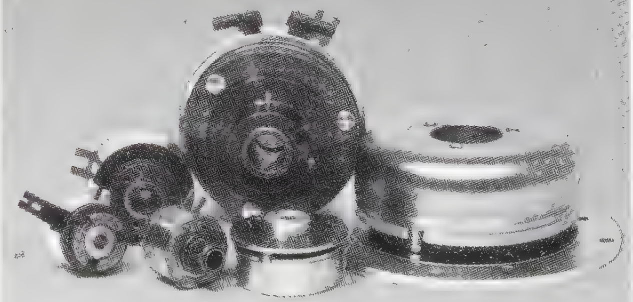
Systems applications tips plus full specifications on precision screw jacks and motorized actuators. Capacities from 250 lbs. to 250 tons.

Get high-quality actuators with **on-time delivery** at highly competitive prices

Circle service number or call 513/294-6261.
FAX 513/294-7631

JOYCE® THE INTELLIGENT CHOICE

Circle 219



Electromagnetic Clutches & Brakes

- Friction and Wrap Spring Clutches up to 175 lb. ft.
- Spring Applied Brakes to 300 lb. in.
- For on-time delivery and quality clutches and brakes, call us today.

INERTIA DYNAMICS
RELIANCE ELECTRIC
Collinsville, CT 06022
1-800-800-6445

Circle 220

When gearing gives you the slip...

S.S. White Technologies, Inc. is your flexible solution.

FREEDOM BY DESIGN S.S. White Technologies Flexible Shaft is the cost effective, reliable way to stay in control or deliver power. Over, under, around and through obstacles. With just one efficient moving part!

- Aerospace reliability at down-to-earth prices
- Eliminates costly U-joints, couplings, gears, pulleys and torque tubes
- Ends alignment, vibration and shock problems
- Withstands or operates in harsh environments
- 0 to 25,000 rpm in seconds

FREE

WE'RE VERY FLEXIBLE

With more than 100 years of flexible shaft experience, we wrote the book on how to put this exciting technology to work. We'd like to learn more about you, so we can send your FREE copy. Please contact Application Engineering, Phone: (908) 752-8300 Fax: (908) 752-8315

S.S. WHITE TECHNOLOGIES, INC.
151 Old New Brunswick Road, Piscataway, NJ 08854-3761

The FORCE in Rotary Motion Flexible Shafts

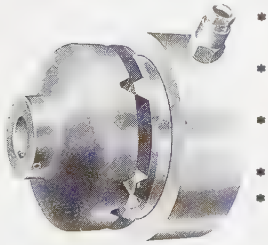
Circle 221

MATRIX ENGINEERING

POSI-RESPONSE

SINGLE POSITION TOOTH CLUTCH

The 7AH-C POSI-RESPONSE single position coupling mount clutch has absolutely no connection between drive *and driven sides.*



FEATURES:

- *CLUTCH AND COUPLING MOUNT TOTALLY SEPARATE*
- *POSITIVE DRIVE WITH NO SLIP*
- *ZERO DRAG WHEN DISENGAGED*
- *SIMPLE SUPPLY CONNECTION*
- *ALWAYS RE-ENGAGES IN SAME POSITION*

Also available is our 7AH-P single position pilot mount tooth clutch.

For complete information please contact:

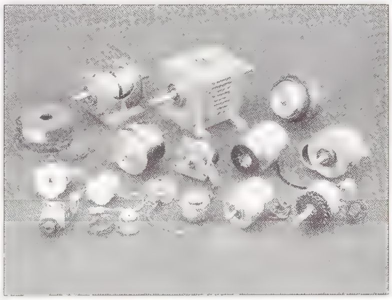
MATRIX ENGINEERING LIMITED
1550 Louis Avenue
Elk Grove Village, IL 60007
Tel: (800)323-1845 Fax:(708)593-0953

Circle 222

DOWNSIZE NOW !!!

OGURA CLUTCH

- Copy Machine
- Tape Drives



- Printers
- Fax Machines

... With Ogura's micro clutches and brakes, Why use oversized, overpriced, old technology for your new machine, when you can use one of Ogura's new micro clutches?

- Complete clutch assembly under 1" diameter in length
- Zero backlash armature
- Ball bearing construction (most sizes)
- Many special designs (gears,sprockets, pulleys, housings,shafts and combination packages) available

Ogura has one of the largest electromagnetic product lines in the world. For more information on this or any other clutch/brake product, please call or write:

OGURA CLUTCH/BRAKE

Kanematsu USA, Inc.
400 Cottontail Lane
Somerset, NJ 08873

Phone (908) 271-7359
Fax (908) 271-7357
WU Telex 130707

Circle 223

material or stress-correction factors.

The space-efficiency concept works best for prestressed power springs, regular power springs, and helical-compression designs. It is not meaningful for some configurations, such as cantilevers and extension springs. For the most efficient design, the amount of space occupied by spring material equals half the space occupied by the spring in the free position. In power springs, it is difficult to estimate the amount of active material and number of turns in the free position because of friction. Consequently, for power springs, ESC is found by estimating or measuring the area under the torque vs. revolution curve.

Indexing mechanisms

Moving an item or conveyor in steps or increments is called indexing. The most versatile indexing devices used dc motors with programmable electronic controls. However, mechanical methods may be more reliable. Some mechanical indexing techniques date to the last century and are not limited to cams, ratchets, and Geneva mechanisms.

IC engines

Most industrial internal combustion (IC) engines in the low-power range, about 30 hp or less, are gasoline powered because diesel engines are too heavy and costly. For example, in a small engine-powered water pump, a gasoline engine would account for perhaps 60% of the cost of the total package. With diesel power, the cost would be closer to 90%.

Thus, in the low-power range, the choice of engine centers largely on such factors as a choice between four and two-cycle operation, and between cast-iron or aluminum construction.

The four-cycle engine is generally the preferred gasoline power plant. It has a reputation for long, trouble-free operation, idles smoothly and operates well at low speeds, does not require lubricant in the fuel, and generally does not have an exhaust with visible smoke.

Small engines are normally air cooled for simplicity and weight savings. However, water cools larger, stationary engines most efficiently.

Up to about 40 hp, four-cycle engines usually have simple L-head valve arrangements, which are less costly than an overhead cam. The overhead-cam arrangement provides more power and fuel economy and is generally found in larger engines.

Small engines use the same simple breathing mechanism and carburetor found on automotive engines. More complicated fuel injection and supercharging is reserved for larger, more expensive engines and for diesels.

Above 10 hp, four-cycle engines are normally made of cast iron. With smaller engines, the buyer has a choice between cast iron and die-cast aluminum. The aluminum engine is less costly if manufactured in large quantities.

Iron is said to wear better, but proponents of the aluminum engine say that it lasts equally long if properly maintained. Iron has a greater tolerance to dirt while dirt ingestion is quite harmful to an aluminum engine.

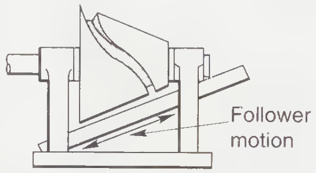
Automotive, marine, and aircraft engines are considerably more sophisticated than small industrial engines, and aluminum is used successfully in large engines in these applications.

The two-cycle engine puts out considerably more power than a four-cycle engine of the same size. The advantage of the two-cycle in power-to-weight ratio runs from 50% to as high as 300% or more. For example, a 40-hp four-cycle engine might weigh 250 lb, while a two-cycle engine of the same power weighs only 65 lb. One 2-cycle engine develops 80 hp from only 440-cc displacement.

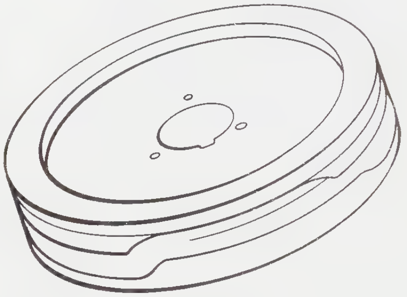
Because of this high-power-to-

CLOSED-TRACK OR GROOVE CAMS

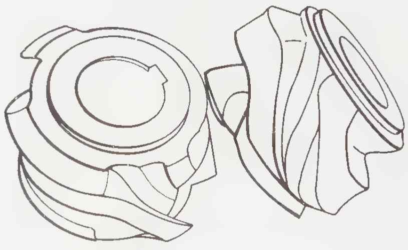
Springs or gravity normally keep a cam follower in contact with the cam surface. But for more positive follower action, the follower rides in a groove or slot in the cam surface.



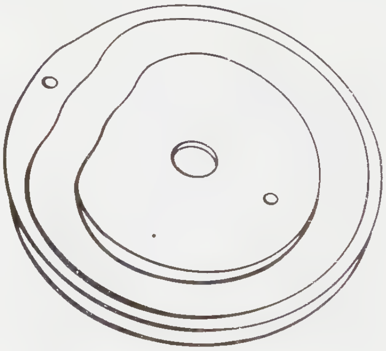
CONICAL CAM TRANSLATING FOLLOWER



BARREL CAM

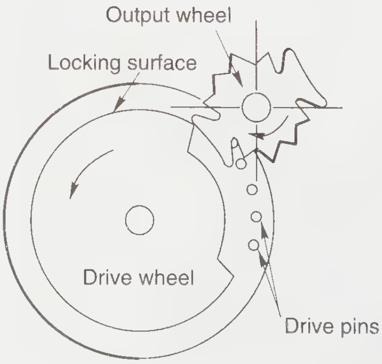


GLOBOIDAL OR RIB CAM



GROOVE OR BOX CAM

STAR WHEELS



This mechanism combines the characteristics of a Geneva mechanism and a mutilated gear. It serves as a Geneva with several driving pins. Most star wheels have circular arcs instead of epicyclically curved slots and use involute gear teeth instead of the drive pins shown here.

There are external and internal types of star wheels. The number of output dwells can range from one to eight for each output revolution, and from one to three for each input revolution. Unlike a Geneva, the star-wheel output can rotate more than one revolution, and it can rotate different amounts at each index point.

weight ratio, the two-cycle engine is generally preferred for sport vehicles or where the engine must be lifted, held, or carried by hand. Power saws and most outboard marine engines are two cycle, as are most snowmobiles.

New developments in this area have automakers rethinking previous two-cycle engine concepts. One research firm found that by finely atomizing the fuel, combustion is more complete, exhaust is clean enough to dispense with the catalytic converter, and idle is more carefully controlled. Because of this, at least one domestic automaker may offer a model powered by a two-cycle engine by 1995.

In other applications, the two-cycle engine has an unfavorable reputation for rough idle, poor operation at low speeds, temperamental behavior, and rapid fouling. Because they tend to operate best at high speed, they may have short service lives. Also, lubricant must be added to the fuel.

To their advantage, first cost is roughly 70% that of an equivalent four-cycle engine made in the same production volume. Two-cycle engines are usually made of aluminum as a weight-saving measure.

Diesels generally become competitive with gasoline engines above 30 hp, and they tend to be a more logical alternative as power demand increases. They are normally chosen because of their operating economy and greater durability. In general, a diesel costs about 2¼ times as much as a gasoline engine, but on the average a diesel lasts about 2¼ times longer. Besides being more costly than gasoline engines, diesels also tend to produce more noise and vibration. Diesels also run over a narrow rpm range and generally require considerable shifting when used in vehicles without torque converters. They require fuel injection, which contributes significantly to their higher cost.

Diesels have acquired their reputation for being rugged heavy engines primarily because they are built to withstand the high firing forces and high cylinder pressures that are a consequence of the high compression needed to produce spontaneous ignition. However, it is possible to build relatively light (and correspondingly less durable) diesels simply by cutting design margins. Some diesels, for example, are built from what are essentially gasoline-engine blocks. Automotive diesels, in particular, tend not to be as heavy or rugged as truck or industrial diesels.

Sometimes the choice of an engine is based on other than economic reasons. The trend toward fuel standardization. for example, often dictates the use of small diesels at installations already using large diesels. The trend toward large diesel-powered farm tractors, for example, is encouraging the use of smaller diesel farm engines so that the only one type of fuel is stored.

Diesel fuel is less volatile than gasoline and, therefore, safer to handle. And diesel fuel is subject to less pilferage than gasoline, a factor causing many building contractors to consider diesel power for small engines. Many companies have standardized on diesel power for all engines; most engines used on oil-drilling rigs are diesel.

Geographic locale can also influence choice of diesel vs. gasoline. European countries, for example, are heavily inclined toward diesel power even for engines well under 30 hp.

As with gasoline engines, there is a choice between two and four-cycle diesels. However, diesels have been perfected and refined to the point where there is little outward functional differences between two and four-cycle oper-

NEED CLUTCHES OR BRAKES?

Call SEPAC ...we've got what it takes to make what you need!

We are motion control problem solvers with the technical and manufacturing skills to design and build the clutch or brake you need!

For information on application or pricing call SEPAC.
800-331-3207
Fax: 607-732-0273

sepac
453 East Clinton Street
Elmira, NY 14901-2552

Tooth Clutches & Brakes
7 Models
13 Sizes
+ Specials

Multiple Disc Clutches & Brakes
12 Models
34 Sizes
+ Specials

Spring Engaged Brakes
4 Models
15 Sizes
+ Specials

Circle 224

ation in terms of power, economy, or durability.

Two-cycle diesel operation requires a mechanical blower to force-feed air so that the engine is aspirated sufficiently. This is in addition to turbochargers (exhaust driven) often used on both four and two-cycle diesels.

The Wankel engine in terms of functional characteristics — including weight, power output, efficiency, and speed — resembles a two-cycle gasoline engine. In short, the Wankel tends to save a bit more weight and space compared to a conventional four-cycle engine. This saving ranges from a trivial amount in small engines, up to a significant amount when compared with a large automotive V8. Here, the Wankel weighs about half as much and has about one-third the size of a four-cycle piston engine.

Over the long term, many researchers expect that the Wankel, with its four-cycle operating principle, may prove to be superior to the two cycle. Originally, the Wankel was plagued by poor combustion-chamber sealing and high fuel consumption. But ongoing development has lead to significant improvements in sealing and reduced fuel consumption.

The Wankel has gained acceptance in some quarters of the automotive market, but currently it is not a contender for industrial applications. However, some large industrial rotary engines have been designed specifically for packaged applications that include compressor, generator, and pump drives. Basically, these rotary engines are high-power low-speed units.

The gas turbine is exceedingly well suited to applications where considerable power output is required at constant speed. For example, one of their most important industrial uses is in driving huge electric generators to augment steam generation under peak demand at power companies. However, gas-turbine engines are expensive both to purchase and operate. (Electric power generated at the utility-company level by a gas turbine costs from three to four times as much as that produced from a steam turbine.)

The cost of a gas turbine is in the range of $15 to $35 per hp, whereas piston engines normally cost in the range of $1 to $10 per hp. The high cost of the turbine stems from the need for expensive materials to withstand the high temperatures generated.

Turbines have poor fuel economy under light load, and they take considerable time to gain speed under acceleration. Thus, they tend to make poor automotive engines. They are better suited to heavy trucks and buses and to high-power stationary applications where they run at a generally uniform high speed.

External combustion Stirling engines are not industrially significant at this time because they have faced stiff competition from well-established internal combustion engines. Moreover, Stirling engines tend to be complex and cumbersome, and are expensive to manufacture.

Nevertheless, there is some interest in this design in automotive circles because of inherent high efficiency and low exhaust emissions. The U.S. government, for example, has sponsored a program with the goal of making the Stirling a fuel-efficient, economical alternative to the IC engine in automotive applications. The first commercial applications, however, for the Stirling engine are in a portable electric generator set for recreational and government-operated vehicles. ■

FINALLY NO MORE COMPROMISES!

Engineered for high speed, high torque applications, Jakob flexible torsion resistant couplings are available in both standard and custom designs. Jakob also offers torque limiting couplings, pulse generators and other motion control components.

- ✓ Torsionally Rigid: Optimizes rotational accuracy and precision.
- ✓ Flexible: Compensates for axial, lateral, and angular misalignments.
- ✓ Quick Installation, Zero Maintenance.
- ✓ Low Inertia: Reduces vibration caused by rapid acceleration, deceleration, or reversing rotation.
- ✓ Zero Backlash: Advanced hub design eliminates keyways.

Call for a free brochure.

JAKOB
Advanced Couplings & Motion Control Components

7317 W. Wilson Avenue
Chicago, IL 60656
Phone: 708/867-7860
Fax: 708/867-8854

Distributed Exclusively By:
GAM ENTERPRISES, INC.

Circle 225

Mechanical fixed and adjustable-speed drives

Speed reducers and transmissions allow one motor design to serve many masters.

Engineers today have the widest variety of transmission types to choose from. That in itself is a blessing and a challenge. The challenge comes from deciding which transmission is most appropriate for an application. While high-power dc drives are very versatile, they can be costly.

A mechanical fixed-speed drive still offers the best combination of a rugged and reliable design with low cost. Many of these transmission technologies seem to overlap. However, one factor, such as lubrication or speed, should set it apart as the clear choice for an application.

Gearboxes

A gearbox may have one or more gear pairs. The gear pairs may be on parallel or nonparallel axes and on intersecting or nonintersecting shafts. If it has more than two pairs, the setup is called a gear train. Generally, they permit higher speed ratios in smaller packages than are feasible with a single pair of gears.

Series trains: Overall ratio is input shaft speed divided by output speed, also the product of individual ratios at each mesh, except in planetary gears. Ratio is most easily found by dividing the product of numbers of teeth of driven gears by the product of numbers of teeth of driving gears.

Planetary gearing: Also called epicyclic gearing. It is a gear train in which a planet gear rotates on its own axis while its axis rotates about another gear called the sun gear. The name epicyclic gearing is derived from the epicycloid curve which is generated by a point on the surface of the planet gear as it rotates about the sun gear. Generally, the more planet gears, the greater the torque capacity of the system. For better load balancing, new designs have two sun gears and up to 12 planetary assemblies in one casing.

Speed reducers: Gearboxes usually offer only a single, fixed-reduction ratio. When they have more than one ratio, they differ from "transmissions" in that the reducer usually is not shifted as often or as easily. As the name implies, a reducer is almost always used to gear "down."

Speed reducers come in two varieties: Base mounted and shaft mounted. The shaft-mounted type, in turn, has two variations. One is truly shaft mounted in that it is supported entirely by the input shaft of the drive machine, with torque reaction absorbed by a special link. The other is mounted to the driven-machine housing so the input shaft does not absorb reducer weight or torque reaction.

By AGMA definition, the term "speed reducer" is applied to units operating at pinion speeds below 3,600 rpm or pitch-line velocities below 5,000 fpm. Reducers operating at speeds higher than these are called "high-speed units."

Catalog ratings and engineering specifications for speed reducers are generally based on AGMA standards.

Speed increasers: These gear-

SHAFT-MOUNTED REDUCERS

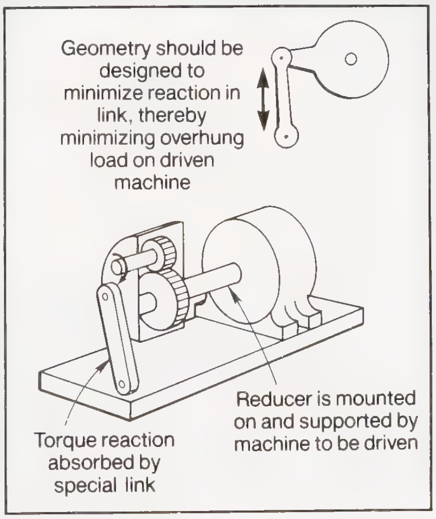
Shaft-mounted reducers are typically combined with a V-belt drive. Standard models cover a spectrum from 10 to 400 rpm, power capacities to 720 hp, and torque capacities to 1,000,000 lb-in.

All shaft-mounted reducers have fixed gear ratios. Output speed can be changed by changing the V-belt ratio. The pulley can be an adjustable sheave if frequent speed changes are necessary.

Ratings and specifications

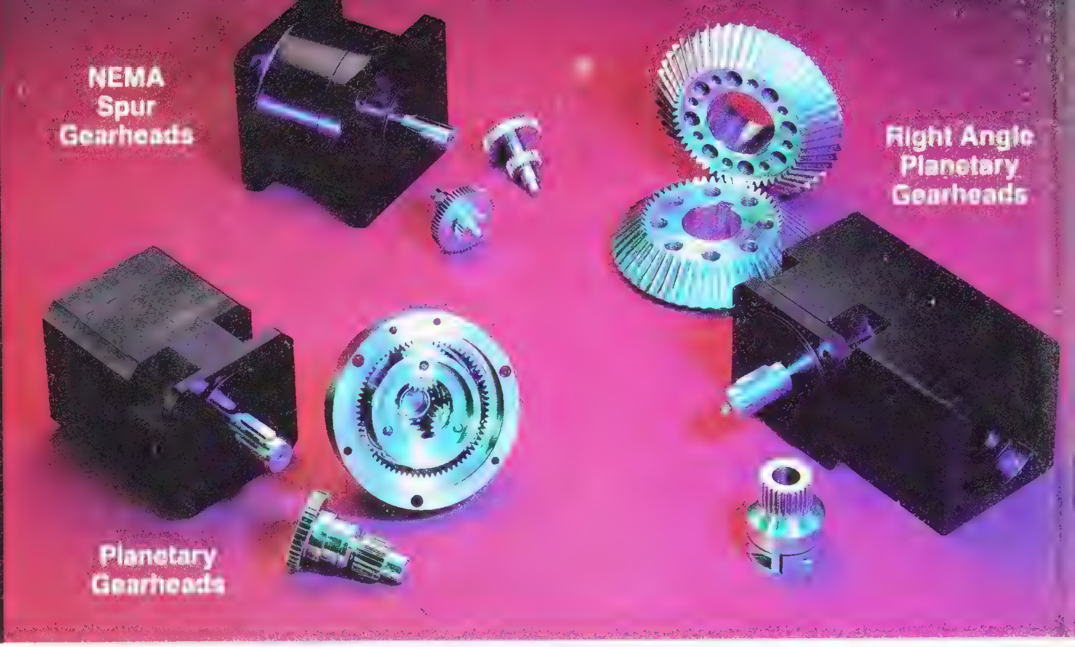
Shaft-mounted reducers are specified and rated in much the same way as are base-mounted reducers; that is, power, speed, and general nature of the application are considered in much the same way. Applicable standards are available from the AGMA for relating loads and duty cycle to service factor.

- Overhung load. In reducers anchored by reaction links, the largest overhung load on the shaft of the driven machine comes from the force on the torque-reaction link. The method for minimizing this force is shown in the illustration. Also, to prevent excessive overhung loads, manufacturers often list a minimum pitch diameter for the V-belt sheave.
- Mounting. A base for standard motor frames is often attached to the reducer housing.
- Overload release. The reaction link in a shaft-mounted speed reducer is easily converted into a torque-limiting device. These devices are usually spring-loaded trips that loosen the V-belt when torque reaction exceeds a preselected value. Most such devices include a limit switch that cuts power to the motor when the mechanism is tripped.


Geometry should be designed to minimize reaction in link, thereby minimizing overhung load on driven machine
Reducer is mounted on and supported by machine to be driven
Torque reaction absorbed by special link

BAYSIDE Precision Gearheads

THE CHOICE IS YOURS

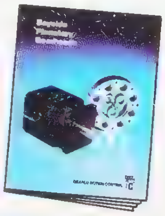


NEMA Spur Gearheads

Bayside NEMA Spur Gearheads offer high precision, low backlash, and very high efficiency, in a compact inline package. These NEMA Gearheads offer the flexibility of a complete range of ratios and sizes, provided ready-to-mount to standard NEMA-face stepper and servo motors. Bayside's Clamp-On Pinion, combined with a wide variety of different motor-mounting packages, makes it easy to attach our NEMA Spur Gearheads to many different motors.

Planetary Gearheads

Bayside Planetary Gearheads provide high torque, low backlash, and high efficiency, in a compact, inline package. With Bayside's Clamp-On Pinion, the Planetary Gearheads mount directly to the face of a wide variety of servo and stepper motors. Available in five frame sizes, and multiple ratios, Bayside Planetary Gearheads are a high performance solution to your gear reduction needs.



Right Angle Planetary Gearheads

Bayside's new Right Angle Planetary Gearheads provide the same high performance features as Bayside's Planetary Gearheads, in a space-saving right angle configuration. High efficiency, high torque, and low backlash are all provided, in five different frame sizes. Bayside's exclusive Clamp-On Pinion makes it easy to attach our Right Angle Planetary Gearheads to a wide variety of servo and stepper motors.

Bayside Gearheads mount to motors from the following companies (Partial list):

AEROTECH
ALLEN-BRADLEY
AMERICAN PRECISION
ANAHEIM AUTOMATION
BALDOR
BEI
BODINE
CLIFTON
CMC TORQUE SYSTEMS
COMPUMOTOR
CONTRAVES
EASTERN AIR DEVICES
EMERSON
FANUC
GETTYS
GIDDINGS & LEWIS (NEXES AUTOMATION)
GME
HITACHI
HONEYWELL
INDRAMAT
INDUSTRIAL DRIVES
INFRANOR
INLAND MOTOR
INTELLICO
LEESON
MAGNETEK
MAXON
MFM
MODICON
MOOG
MTS
NYDEN
ORIENTAL MOTOR
ORMEC
PACIFIC SCIENTIFIC
PARVEX
PITTMAN
PMI
PORTESCAP
RELIANCE MOTION CONTROL (ELECTRO-CRAFT)
SIEMENS
SUPERIOR ELECTRIC
TOSHIBA
VICKERS
WHEDCO
YOKOGAWA
YASKAWA

Our experienced engineers are ready to answer your application questions. For application help, or for a color catalog call:

BAYSIDE CONTROLS INC. • 27 SEAVIEW BOULEVARD • PORT WASHINGTON, NY 11050
TEL: (516) 484-5353 • FAX: (516) 484-5496

BAYSIDE CONTROLS INC.
BCI

Circle 226

BAYSIDE PRECISION GEARHEADS

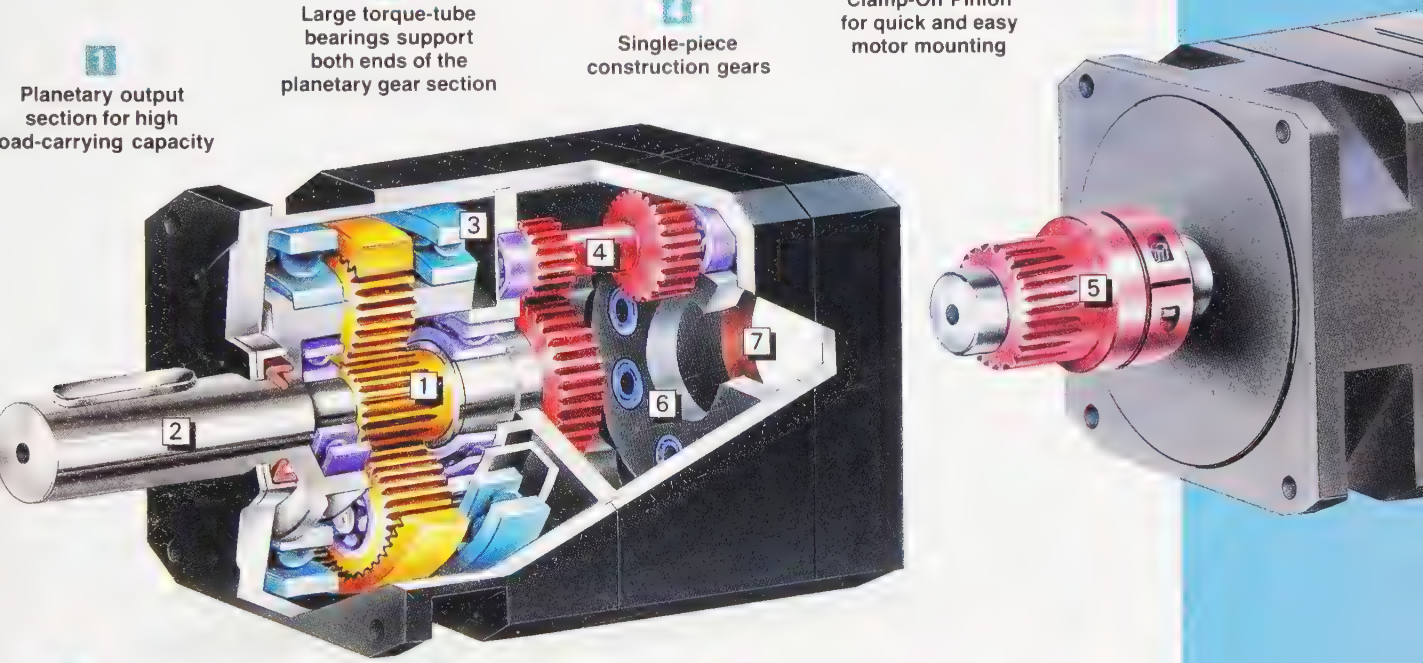
The only Planetary Gearheads that give you high torque, low backlash, and a lot more

1 Planetary output section for high oad-carrying capacity

3 Large torque-tube bearings support both ends of the planetary gear section

4 Single-piece construction gears

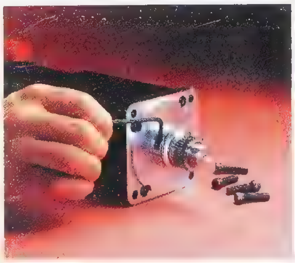
5 Clamp-On Pinion for quick and easy motor mounting



2 Output shaft and anet carrier made n a single steel bar

6 Exclusive spur gearhead input section eliminates difficult motor pinion alignment

7 Waterproof seals throughout



Quick, easy mounting to servo and stepper motors . . . unique Clamp-On-Pinion™ makes gearhead attachment to a motor as simple as tightening an Allen screw and four bolts

☐ Backlash as low as 5 minutes
☐ Peak torques to 15,000 in-lbs.
☐ 5 frame sizes: 60, 90, 115, 142 & 180mm.
☐ Ratios from 5:1 to 100:1

Available for immediate delivery.
Made in USA.

Please call, fax or write for free color brochure:

BAYSIDE CONTROLS INC. • 27 SEAVIEW BOULEVARD • PORT WASHINGTON, NY 11050 • TEL: (516) 484-5353 • FAX: (516) 484-5496

GEARED MOTION CONTROL

BAYSIDE CONTROLS INC.
BCI

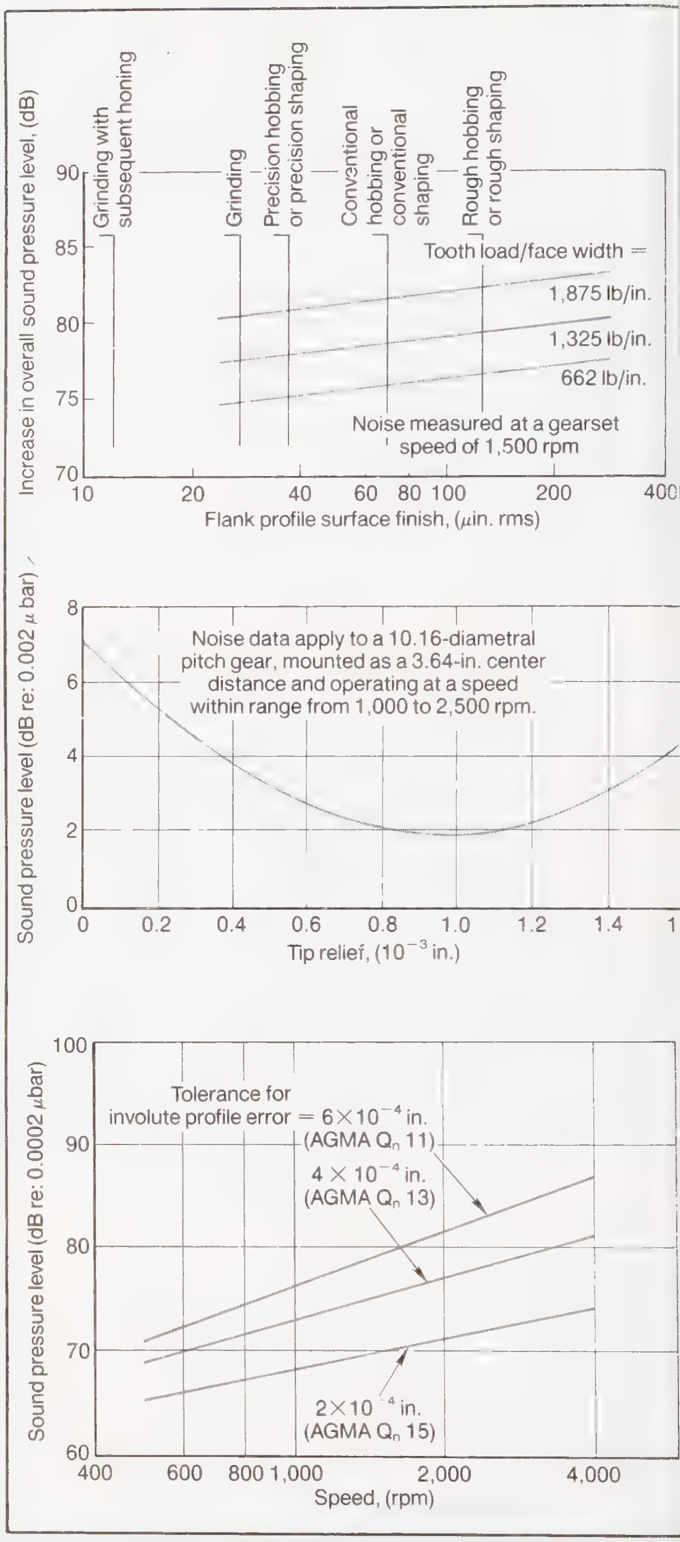
GEARSET ACCURACY AND CONTACT RATIOS

Usually improved kinematic accuracy in a gearset decreases gear mesh excitation and results in lower drive noise. Gearset accuracy can be increased by modifying the tooth involute profile, by substituting higher quality gearing with tighter manufacturing tolerances, and by improving tooth surface finish. However, if gear mesh excitation generates resonance somewhere in the drive system, nothing short of a "perfect" gearset will substantially reduce vibration and noise.

Tooth profiles are modified to avoid interferences which can result from deflections in the gears, shafts, and housing as teeth engage and disengage. Gear load capacity can be seriously reduced if there is no profile modification to compensate for these tooth interferences. In addition, the drive will be noisier because tooth interferences generate high dynamic loads. Interferences typically are eliminated by relieving the tooth tip, the tooth flank, or both. Such profile modifications are especially important for high-load, high-speed drives. The graph of sound pressure level (SPL) vs. tip relief illustrates how tooth profile modifications can affect overall drive noise. The graph shows that for the given drive configuration, there is an optimum amount of tip relief — in this case, 0.001 in. — yielding a minimum noise level. If the tip relief is less than this optimum value, drive noise increases because of greater tooth interference; a greater amount of tip relief also increases noise because the contact ratio is decreased.

Tighter manufacturing tolerances also produce quieter gears. Tolerances for such parameters as profile error, pitch error, and lead error commonly are classified according to AGMA quality levels. For instance, the graph depicting SPL versus both speed and gear quality shows how noise decreases with increasingly smaller tolerances for profile error. In this example, noise is reduced significantly by an increase in accuracy from an AGMA Q_n 11 quality to an AGMA Q_n 15 quality. However, for most commercial drive applications, it is doubtful that the resulting substantial cost increase for such an accuracy improvement can be justified simply on the basis of reduced drive noise.

Usually, tighter tolerances will provide greater noise reduction for low-quality gearing than it will for high-quality gearing. For example, given that all operating conditions remain the same, an accuracy improvement from AGMA Q_n 8 quality to Q_n 11 quality typically provides a greater noise reduction, than an improvement from AGMA Q_n 13 quality to Q_n 15 quality. Moreover, the cost increase of a quality improvement from AGMA Q_n 8 class to Q_n 11 class is relatively small, compared to the cost of a quality change from AGMA Q_n 13 class to Q_n 15 class. Consequently, gear accuracy improvements for lower quality gears usually prove to be a cost-effective way of reducing drive noise.



Improvements in tooth surface finish have only a minor effect on noise reduction. The graph of SPL as a function of both surface finish and the ratio of tooth load and face width illustrates how only small SPL reductions result for relatively great improvements in surface finish. For example, an improvement in tooth surface finish from about 70-μin. rms to 25-μin. rms yield only about a 1-dB reduction in noise level. Such an improvement in surface finish can be obtained by changing from a conventionally hobbed gear to a hobbed and ground gear. Depending on gear size and gear type, improvement of tooth surface finish in this manner can increase cost by as much as two and a half times. Therefore, it is unlikely that such a modification can be justified on the basis of noise reduction alone. Fortunately, however, a change from conventional hobbing to finish grinding also improves other gear parameters that affect noise. As a result, the total reduction in noise level is greater than the reduction due to improved surface finish alone.

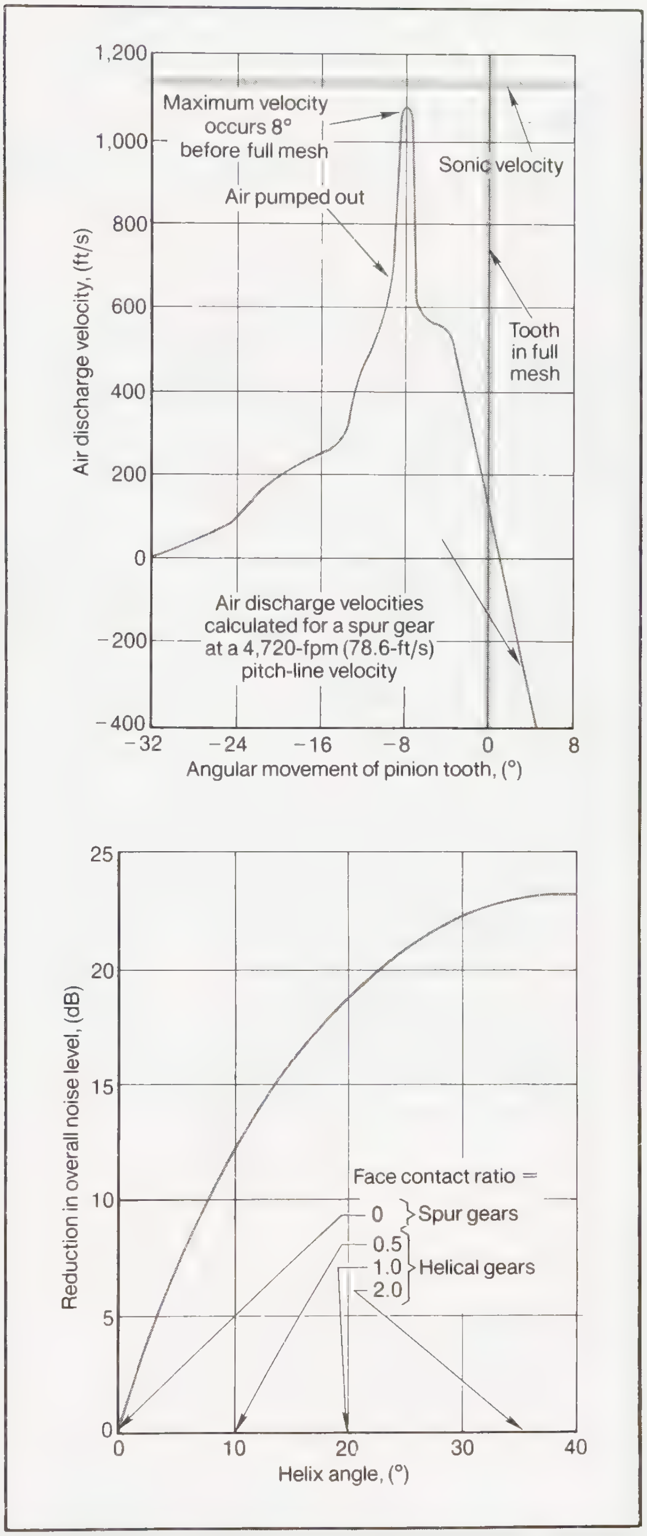
Previously, it was mentioned that gears must have adequate clearance when loaded to prevent tooth interference when meshing. Tip and flank relief are common profile modifications that control such interference. Gears also require adequate backlash and root clearance. Noise considerations make backlash an important parameter to evaluate during drive design. Sufficient backlash must be provided under all load and temperature conditions to avoid a tight mesh, which creates excessively high noise levels. A tight mesh due to insufficient backlash occurs when the drive and coast side of a tooth are in contact simultaneously. On the other hand, gears with excessive backlash also are noisy because of impacting teeth during periods of no load or reversing load. Adequate backlash should be provided by tooth thinning rather than by increases in center distance. Tooth thinning does not decrease the contact ratio, whereas an increase in center distance does. However, tooth thinning does reduce the bending-fatigue strength, a reduction which is small for most gearing systems.

For drives operating at high speeds, relatively small increases in backlash can reduce noise resulting from the discharge of air and oil trapped in the mesh. Spur gears probably are most susceptible to this noise-producing phenomenon. As shown in the diagram depicting discharged air velocity vs. pinion angular movement, trapped air is discharged out of a high-speed mesh at a velocity that is many times the pitchline velocity of a gear set and which can approach sonic velocity. At sonic velocity, such discharge of trapped air and oil dominates the overall noise level of a gearbox. Consequently, all noise reduction efforts will prove fruitless if this phenomenon is not recognized and dealt with. The same noise-reducing mechanism also can occur in wide-faced gears operating at moderate to high speeds. The increase in backlash required to decrease discharge velocity is a function of the tooth form, face width, and gear type.

Additional root clearance also helps reduce the discharge velocity of trapped air and oil. Greater root clearance can be obtained by increasing the tooth whole depth. Such a modification will increase tooth compliance, increase load sharing, and improve error tolerance. However, greater root clearance also increases tooth bending stress. Therefore, the benefits of noise reduction must be weighed carefully against the potential loss in tooth strength.

Drive noise also can be reduced by increasing the contact ratio. An increase in contact ratio reduces the total load carried by any single pair of teeth, thereby also reducing the dynamic forces generated at engagement and disengagement. In addition, as the number of tooth pairs in contact increases, individual tooth errors tend to average out, also reducing dynamic loads. Almost all other gear tooth parameters which are said to affect noise level do so largely by virtue of their effect on contact ratio. For example, a reduction in the pressure angle of spur gears increases the contact ratio and, in turn, decreases noise. Similar improvements in contact ratio and noise reduction also can be obtained by lengthening the addenda slightly.

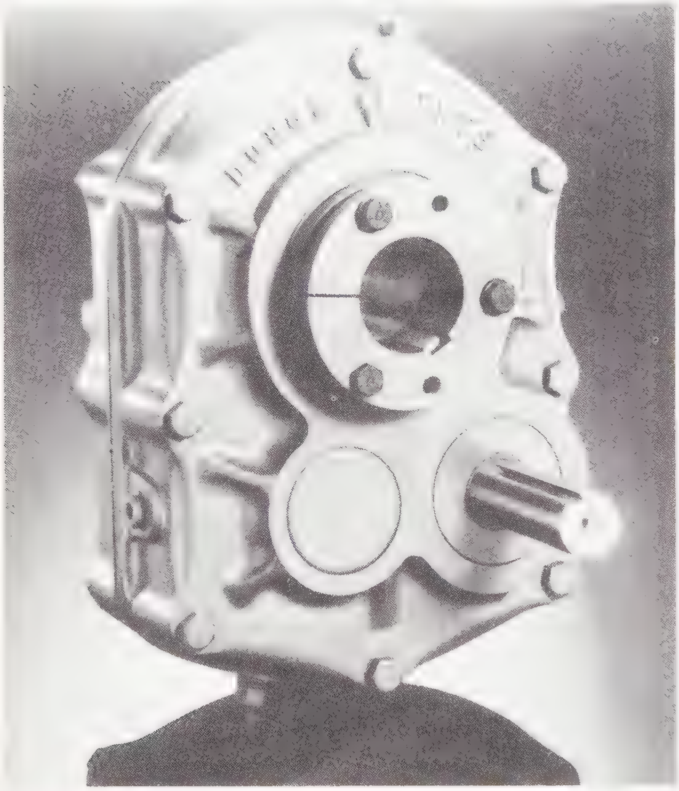
Lower pressure angles not only increase the contact ratio but also compromise tooth strength because they reduce tooth stiffness. This increased tooth compliance lowers dynamic tooth loading and further decreases noise. If the diametral pitch is increased, gears also will be quieter because of a greater contact ratio. Most of the resulting noise reduction with lower pressure angles and finer pitch, however, is due to the increase in contact ratio — especially for contact ratios in the range of 1 to 3 — rather than due to greater tooth compliance.



One of the simplest ways of improving contact ratio is to use helical and spiral-bevel gears rather than spur and straight bevel gears. The graph of noise reduction vs. helix angle illustrates the effect of a change from spur to helical gears. Given that the center distance, face width, number of teeth, torque, and speed remain constant, noise level drops with an increase in helix angle because of the resulting increase in face contact ratio. Reduction of noise for gears with high helix angles, however, tends to level off because of the difficulties in manufacturing and mounting such gears accurately to take full advantage of the improvement in contact ratio. Helix angles greater than 45° generally are impractical to manufacture and consequently are seldom used.

DODGE® TORQUE-ARM

America's #1 Shaft Mounted Speed Reducer



GENERAL DATA:

- **A compact, high-efficiency enclosed helical gear reducer mounted directly to a driven shaft with positive grip tapered bushings.**
- **1/4 to 700 HP.**
- **1 to 400 RPM output.**
- **3/4″ to 10″ bores.**
- **5:1, 9:1, 15:1, and 25:1 gears; drive ratios 210:1 with V-belt drives.**

NEW

DODGE®

T-A DISCovery™

Computer Selection of TORQUE-ARM™ Speed Reducers and Accessories

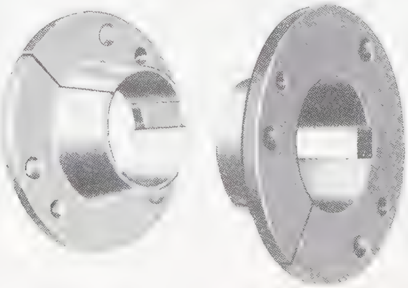
The DODGE® TORQUE-ARM DISCovery program provides an easy means of applying and selecting TORQUE-ARM Gear Reducers. Selection logic has been programmed, allowing the user to select basic inputs from easy-to-use menus to get complete product selection data.

The purpose of the program is to save time required in making a gear reducer selection. Given accurate service factor input data, the TORQUE-ARM DISCovery program matches your drive requirements with a specific TORQUE-ARM product. The out-put screen provides all pertinent engineering and ordering data on each selection.

DESIGN FEATURES:

Twin Tapered Bushings

- Exclusive twin tapered bushings provide a positive, concentric grip on both sides of the reducer. These twin tapered bushing are made of ductile iron and are fully split to allow the bushing to completely collapse around the driven shaft. As the bushing screws are tightened into the back-up plate, the bushing is wedged inward. It contracts evenly and grips the shaft. To dismount, simply insert screws in the threaded holes in the bushing flange. As they are tightened they act as jacking screws to free the bushing. No puller is required; the reducer comes right off.



Speed Ratios Easily Obtained

- TORQUE-ARM reducers, combined with V-belt drives may provide any speed ratio up to 210:1...with output speeds thru 400 RPM. Quick adjustment of the V-belt is made through the use of a turnbuckle on the TORQUE-ARM, which anchors the reducer, or via the use of a motor mount with adjusting screws.

Cast Iron Housing

- TORQUE-ARM housings are cast of corrosion-resistant gray or ductile iron which permits a better design than is possible in fabricated unit. Thickness and rib structure are varied to add strength where strength is needed according to size and load. Long life and trouble-free service result. To achieve alignment, the two halves of the reducer housing are bolte together, doweled and precision bored.

igh Performance Gears

Tremendous advances have been made in gear design in recent years, and the present efficiency of 98% per gear set in DODGE speed reducers is the result of the most efficient helical gear design known. All TORQUE-ARM gears are helical design and crown shaved to provide an ellipsoid tooth to eliminate tooth end bearing and assure meshing at the strongest tooth area. All gears are case carburized to insure a high surface durability with a resilient tooth core for greater impact resistance and longer gear life. Gears are supported between bearings to maintain proper alignment on gear meshes, to maximize load carrying capabilities, and to eliminate overhung loads imposed on bearings.

eliable Anti-Friction Bearings

Bearings are sized to conform with the Anti-friction Bearings Manufacturers Association Bearing Ratings. All bearings provide 25,000 hours average life.

Double-Lip Seals

- Metallic double-lip seals keep lubricating oil in, lock dirt and contaminants out. The cavity between the inner and outer lips is filled with grease at assembly to prelubricate the seal. A garter spring exerts a constant, gentle pressure at every point around the circumference of the shaft to insure a positive seal. All seals ride on precision ground surfaces for maximum life.

Lubrication

- Splash lubrication system adds to reducer life by allowing a continuous flow of oil to bearings and gears, thus insuring smooth, cool and efficient operation with minimum friction and heat build-up. A quality petroleum base oil containing anti-foamants and rust inhibitors should be used.

Optional Accessories

- Full line of accessories: Motor Mounts, Backstops, Auxiliary Seals, Tri-Matic Overload Release, Mounting Brackets, V-belt Drives and Belt Guards.

DODGE TORQUE-ARM PRODUCT LINE

Taper Bushed Reducer	Maximum Bore	A.G.M.A. Code	Input H.P. at 75 rpm Output 15:1 & 25.1	Input H.P. at 100 rpm Output 5:1	Taper Bushed	Straight Bore	Hydroil Style	Vertical Style	Motor Mount	Backstop	Flange Mounting Pads	Trimatic Overload Release	Taconite Auxiliary Seals	Floor Mounting Brackets	Seal Kits
TXT1	1 [illegible]/16	107	4.15	4.49	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TXT2	1 15/16	115	7.52	7.00	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TXT3	2 3/16"	203	10.46	10.00	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TXT4	2 7/16"	207	16.70	15.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TXT5	2 15/16"	215	25.00	24.38	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TXT6	3 7/16"	307	37.90	38.19	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TXT7	3 15/16"	315	56.96	56.71	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TXT8	4 7/16"	407	81.98	90.01	Yes	Yes	—	Yes	Yes	Yes	Yes	Yes	Yes	Consult Factory	Yes
TXT9	4 15/16"	415	125.0	127.81	Yes	Yes	—	Yes	Yes	Yes	Yes	Yes	Yes	Consult Factory	Yes
TXT10	5 7/16"	507	185.0	—	Yes	Yes	—	Yes	Yes	Yes	Yes	Yes	Yes	Consult Factory	Yes
TXT12	6 1/2"	608	275.0	—	Yes	—	—	Yes	Yes	Yes	Yes	—	Yes	Consult Factory	Yes
TDT13	7"	700	374.0	—	Yes	—	—	Yes	Yes	Yes	Yes	—	Yes	Consult Factory	Yes
TDT14	8"	800	561.0	—	Yes	—	—	Yes	Yes	Yes	Yes	—	Yes	Consult Factory	Yes
TDT15	10"	1000	—	—	Yes	—	—	Yes	Yes	Yes	Yes	—	Yes	Consult Factory	Yes

Specify DODGE TORQUE-ARM.
Move faster with the leader.™

ODGE / P.O. Box 499 / 2 Ponders Court / Greenville, S.C. 29602-0499 / 803-297-4800 / FAX: 803-281-2318

Reliance Electric Company, 1990

Circle 227

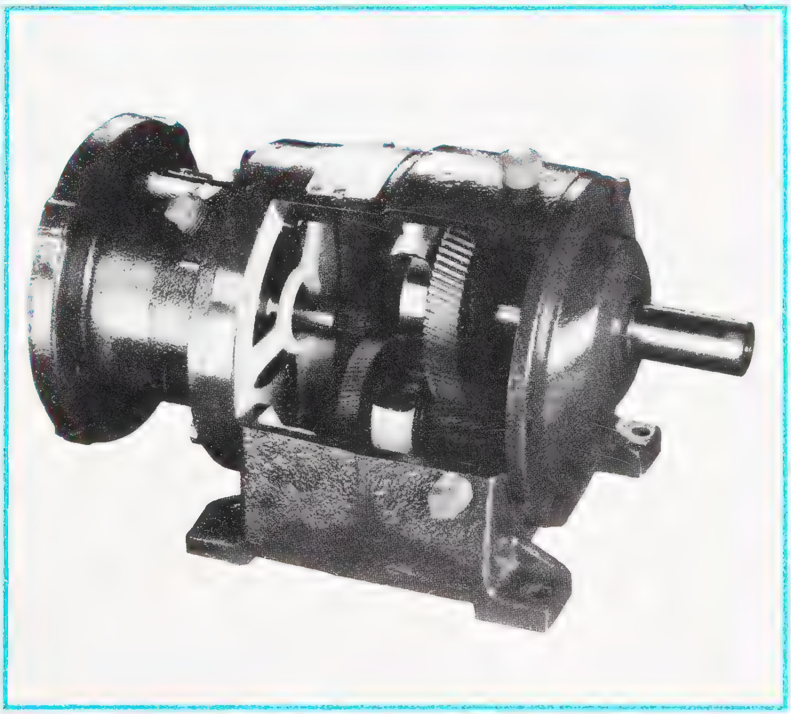
RELIANCE ELECTRIC

AMERICAN PARALLEL GEARING

DODGE APG

The World's Greatest Power Density

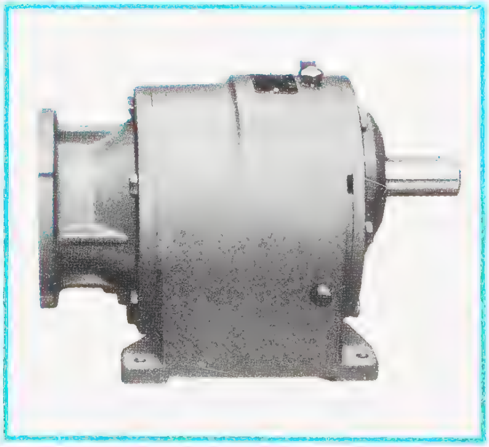
- Gearmotors
- C-Face Reducers
- Shaft-In Reducers



Fractional thru 75 HP
1.22 thru 129.7 Helical Reductio

Designed For Your Needs

- Power dense design delivers more for a lowe initial cost.
  - Reduced helix angle on gears
  - Short bearing spans
  - AGMA Class 9 carburized and ground gear
- APG is user friendly for lower operational cos
  - USDA H2 approved factory-filled premium lubricant
  - One oil change per year
  - Pry slots and dowels on covers
  - Easy access to gears and seals
  - Patented C-face coupling
  - Washdown option available
  - USDA approved finish



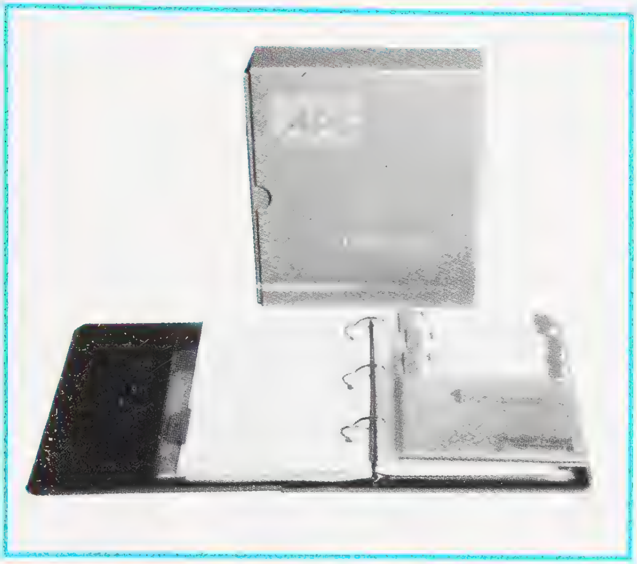
What this means to you is:

- Higher profits through reduced initial and operating costs
- Less time spent on maintenance and repair
- A stronger America

DODGE®
Eliminates
The Grunt
Work!

DODGE
APG DISCovery™

DMR SOFTWARE™—PC Product Selection and Application Programs and PC Electronic Template Drawings



APG Saves Design Time!

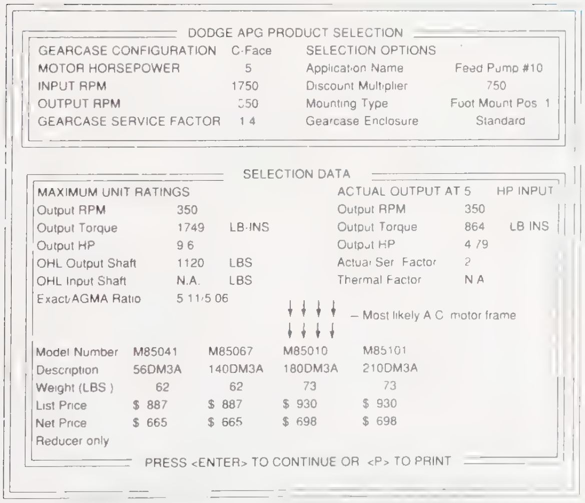
With the APG Designer's Guide* you can make a selection and drawing in minutes!

The Designer's Guide Includes:

- General Specifications
- Cutaway Photographs
- APG DISCovery Selection Program
- FIRST LINE Electronic Templates
  - C-Face and Separate Reducers
  - C-Face Motors
- Complete Maintenance and Repair Instructions

APG DISCovery™

makes selection and documentation easy!

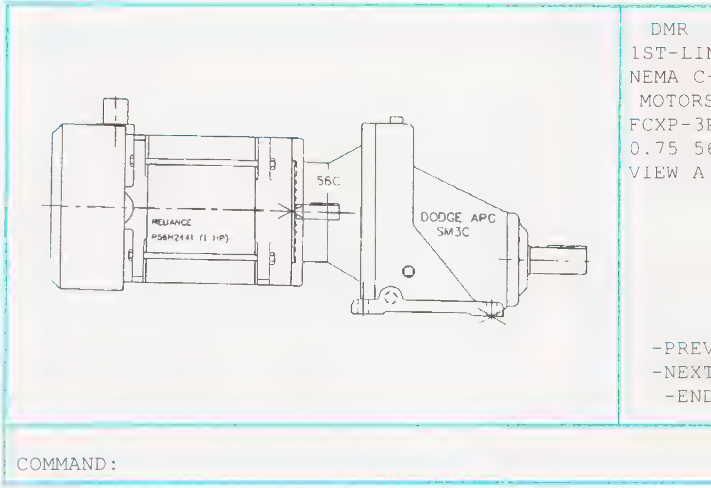


```
                  DODGE APG PRODUCT SELECTION
GEARCASE CONFIGURATION    C-Face    SELECTION OPTIONS
MOTOR HORSEPOWER            5       Application Name      Feed Pump #10
INPUT RPM                 1750      Discount Multiplier        750
OUTPUT RPM                 350      Mounting Type         Foot Mount Pos  1
GEARCASE SERVICE FACTOR    1 4      Gearcase Enclosure       Standard

                        SELECTION DATA
MAXIMUM UNIT RATINGS                    ACTUAL OUTPUT AT 5     HP INPUT
Output RPM          350                 Output RPM        350
Output Torque       1749    LB-INS      Output Torque     864    LB INS
Output HP           9 6                 Output HP         4 79
OHL Output Shaft    1120    LBS         Actual Ser  Factor  2
OHL Input Shaft     N.A.    LBS         Thermal Factor    N A
Exact/AGMA Ratio    5 11/5 06
                                  ↓ ↓ ↓ ↓   — Most likely A C  motor frame
                                  ↓ ↓ ↓ ↓
Model Number     M85041     M85067     M85010     M85101
Description      56DM3A     140DM3A    180DM3A    210DM3A
Weight (LBS )      62         62         73         73
List Price       $  887     $  887     $  930     $  930
Net Price        $  665     $  665     $  698     $  698
Reducer only
          PRESS <ENTER> TO CONTINUE OR  <P> TO PRINT
```

DODGE® FIRST LINE™
Electronic Templates For Design

makes drawing and accessory mounting easy!



```
 DMR
1ST-LIN
NEMA C-
 MOTORS
FCXP-3F
0.75 56
VIEW A

 -PREV
 -NEXT
  -END

COMMAND:
```

*Requires IBM® compatible personal computer and AutoCAD®, Microcadam®, or ANVIL 1000 MD® CAD software for operation.

Specify DODGE APG.
Move with the leader

DODGE / P.O. Box 499 / 2 Ponders Court / Greenville, S.C. 29602-0499 / 803-297-4800 / FAX: 803-281-2318

© Reliance Electric Company, 1990

RELIANCE ELECTRIC

Circle 228

E-Z KLEEN™ TIGEAR® REDUCERS

NEW

Sizes 150 thru 262
Frames 56C and 140TC
All Ratios

DODGE E-Z KLEEN TIGEAR is designed to survive in harsh environments and clean up like new. DODGE E-Z KLEEN TIGEAR is especially well suited for wet applications and where frequent washdown is required.

E-Z KLEEN TIGEAR Features Include:

- Cast iron housings coated with corrosion, chemical and abrasion resistant white Nylon 11
- Stainless steel nameplates, fasteners and freeze plugs
- Rubber covered or stainless steel output seals
- Electroless nickel plated output shafts
- Smooth contours on all surfaces
- Footless multimount gearcase
- The RELIALUBE® system for pressure relief with no open path to the environment
- No periodic maintenance required except cleaning
- Factory filled U.S.D.A. Class H-2 approved synthesized hydrocarbon lubricant

E-Z KLEEN TIGEAR Reducers are stocked in component form for assembly and shipment within 2 to 4 weeks from the factory in Columbus, Indiana.

DODGE®

Move faster with the leader.™

DODGE/P.O. Box 499/2 Ponders Court/Greenville, S.C. 29602-0499/803-297-4800

DODGE®, TIGEAR®, E-Z KLEEN™ and RELIALUBE® are trademarks of Reliance Electric Company or its affiliates.

© Reliance Electric Company, 1991

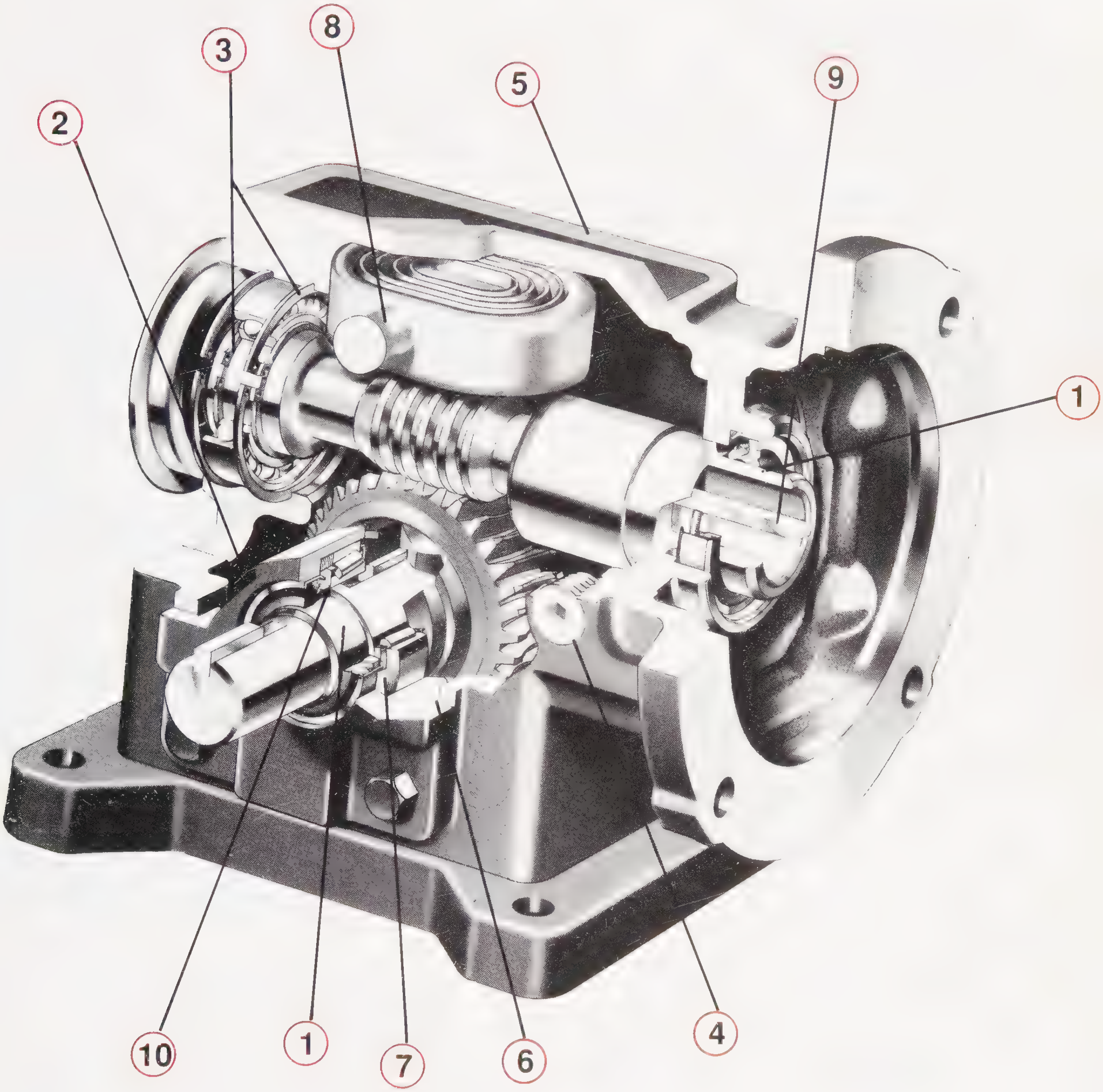
RELIANCE ELECTRIC

Printed in U.S.A.

DMR-320-1

4/91 20M-K

DODGE® TIGEAR® Reducers Built-In Features



Plunge ground seal journals—15 micro finish.

Dead spot flats—free from sump turbulence to accumulate wear particles.

Oversized standard snap rings on input bearing to accommodate thrust loading on inner and outer race, both sides.

Minimized leak paths.

Stainless pinned nameplate. (Back of unit)

Deep pilot bores for improved sealing.

⑦ Shimming behind output roller bearing cups centers the gear, accommodates tolerance stackup, won't cut fingers or create laminations for leakage.

⑧ Molded O-ring in compression chamber neck along with expanding tines in the breather core to eliminate leakage.

⑨ Swedge fit factory-installed input key—stays tight to solve motor mounting problems and reduce key wear.

⑩ Zero interference dirt lips on double lip seals.

Circle 229

Reeves®
Excellence Since 1888

DODGE

REEVES PROCESSING SPECIAL

FOOD – CHEMICAL – WASTEWATER TREATMENT

GENERAL SPECIFICATIONS

Construction: All external parts of cast iron.*

Finish: USDA approved white paint.

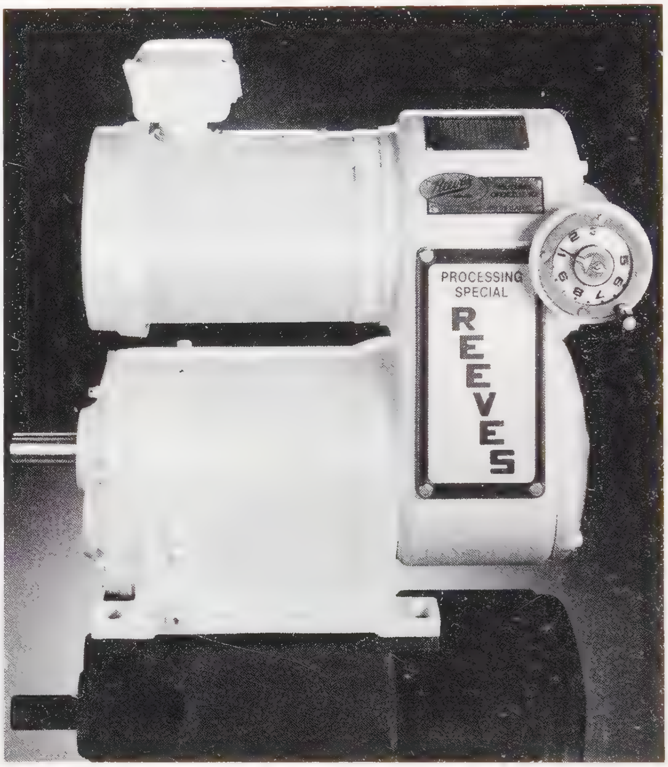
Motor: NEMA C-Face dimensions
EZFC (Easy Clean Fan Cooled) thru 25 HP,
XTFC (Extra Tough Fan Cooled) for 30 and 40 HP.

Belt Case:
- Corrosion Resistant Hardware
- Gasketed Inspection Plates
- Double Lip Shaft Seals
- Splash-Proof Reducer Vent
- Stainless Steel Name/Inspection Plates
- Condensation Release Ports

Discs: Chrome-Plated

Shafts: Chrome-Plated in disc contact areas

*In case size 050 the bearing plate and the control housing cover are in epoxy-painted cast aluminum. In addition, some of the handwheel parts are not of cast iron.



Stock MOTO DRIVE® Processing Specials

Discount D-49a

Stock MOTO DRIVE Processing Specials with Parallel Gearing

HP[1]	Size	Ratio	RPM Max.	RPM Min.	Mounting[2] Assembly	Ordering Number	List Price $
1/2	051	3.4:1	1440	144	101	M05H1001	1578
3/4	113	44.0:1	106	10.6	105	M10H1001	2036
1	112	9.7:1	433	48	105	M10H1002	2059
1 1/2	111	3.93:1	1069	118	101	M10H1003	2181
2	221	6.2:1	680	68	101	M20H1001	3121
3	222	7.6:1	550	55	105	M20H1002	4163
5	332	9.3:1	450	45	105	M30H1001	5766

1. All motors are EZFC, 3 phase, 230/460 volts, 60 Hz.
2. All stock handwheels furnished in W position.

Stock MOTO DRIVE Processing Specials with Right Angle Gearing

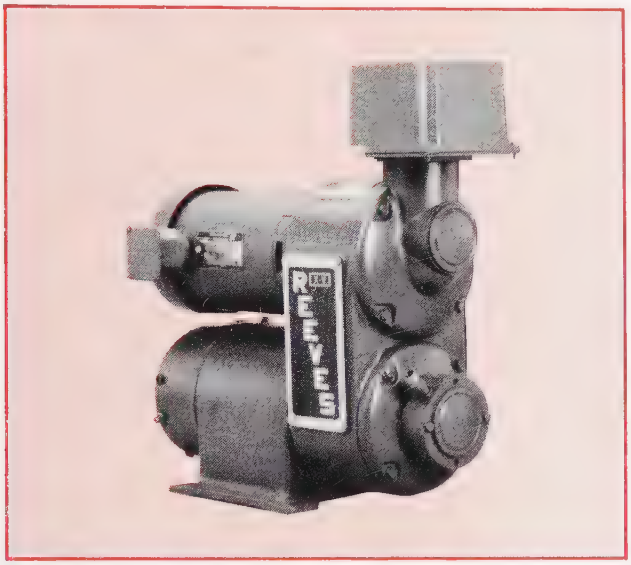
HP[1]	Size	Ratio	RPM Max.	RPM Min.	Mounting[2] Assembly	Ordering Number	List Price $
1/2	1C21	288:1	16.2	1.62	170-K1	M10H1004	2000
3/4	1W21	40.0:1	117	11.7	170-K1	M10H1005	1925
1	1W21	40.0:1	105	11.7	170-K1	M10H1006	2139
1 1/2	1C16	70.0:1	60	6.66	170-K1	M10H1007	2542
2	2C21	50.0:1	84	8.4	170-K1	M20H1003	3615

REEVES Processing Specials are available on all catalog ratings. Contact your DODGE Sales Engineer or use the Volume 2.1 DODGE Gear Engineering Catalog.

Reeves®
Excellence Since 1888

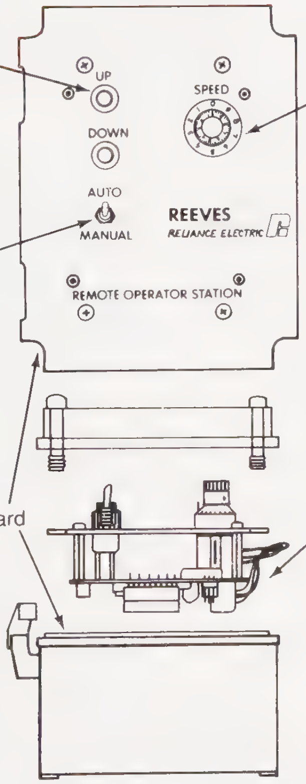
DODGE®

AUTOMATIC CONTROLLERS



User Friendly Features:

- **Easy to Apply**—The REEVES MOTO DRIVE and Reducer combination is cataloged by output speed and horsepower. A complete variable speed package.
- **Easy to Control**—The RAC controller includes a ten-turn potentiometer for local control. Plus, jumpers are included to allow RAC to follow any standard analog control signal such as 0-10 VDC or 4-20 ma.
- **Accurate and Repeatable**—Built-in closed-loop control insures better than ±1% accuracy (of set speed). Adjustable dead band.
- **Adaptable**—All controller electronics mounted on a removable subpanel. Easily remountable in user's panel.
- **Environment**—NEMA 4X control head standard. All drive-mounted hardware suitable for washdown. Hazardous duty capability.
- **No Interference**—Transformer-powered analog circuitry means freedom from EMI or RFI generation. No computer hash.
- **Easy to Install**—Only 4 small gage wires required to connect the MOTO DRIVE unit and the control head.
- **Easy to Retrofit**—Kits are available for field retrofit of existing drives. Extremely cost effective.
- **LED Indicators**—LED indicators demonstrate drive speed stable or shifting.
- **Minimum and Maximum Speed Limit Adjustment**—On-board adjustment pots provide limits in both automatic and manual modes (adjustable zero and span).



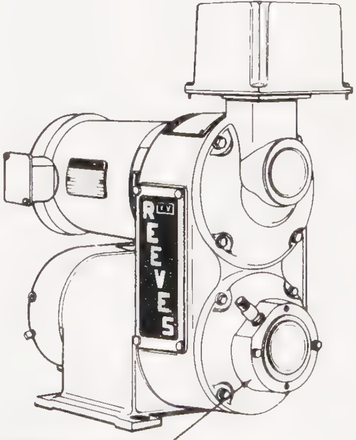
LED OPERATION INDICATORS
"Up" indicates increasing speed, "Down" indicates decreasing speed.

10-TURN SPEED POTENTIOMETER
Equipped with logging scale, for controlling speed in manual mode.

AUTO/MANUAL SELECTOR SWITCH
To select internal or external speed reference.

NEMA 4X
Enclosure Standard

PRINTED CIRCUIT BOARD
Contains the complete logic, along with the adjustments for minimum speed, maximum speed, reference signal selector, and sensitivity (deadband).



SERVOMOTOR
Accepts signal from control unit to appropriately position sliding belt discs in MAS unit.

MAGNETIC PULSE PICK-UP SYSTEM
Provides closed-loop feedback signal to control unit to confirm operating speed.

Specify REEVES®
Move faster with the leader.™

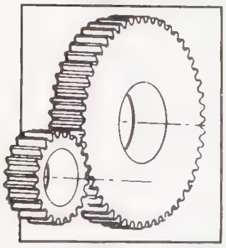
/ P.O. Box 499 / 2 Ponders Court / Greenville, S.C. 29602-0499 / 803-297-4800 / FAX: 803-281-2318

RELIANCE ELECTRIC

© Reliance Electric Company, 1990

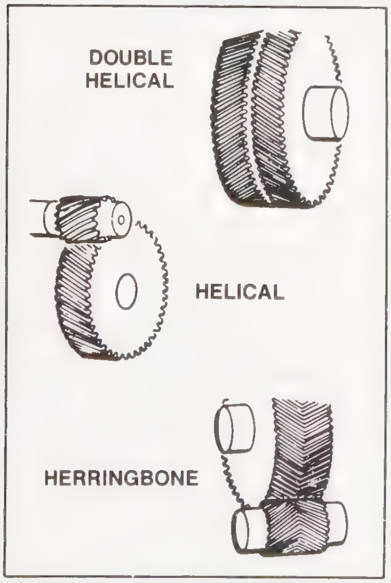
GEAR DESIGNS FOR DIFFERENT DUTY

The involute tooth form is the oldest and most versatile for gears because it is easily machined, as well as altered, for custom applications. Most nonproprietary gear types are spur or helical. While each can be cut with the same tooling and machinery, each design has advantages.

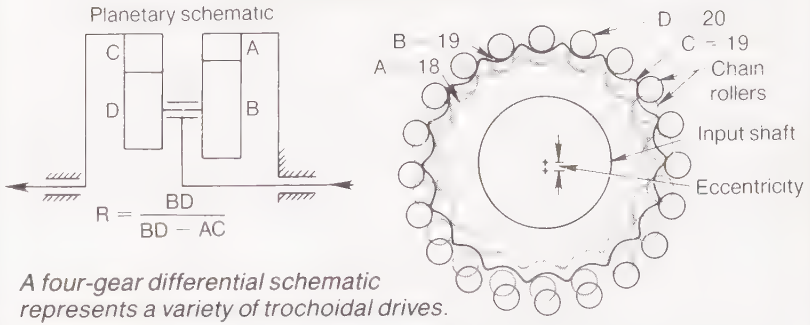


Spur: The most common type. Teeth are straight and parallel to shaft axis. Advantages: simple, low cost, easy to maintain. Drawbacks: less capacity and are noisier.

Helical: Carry more load than equivalent-size spur gears. Can also be made to operate more smoothly and more quietly. Drawbacks: may be more costly than spur gears; single helical develops end thrust (which increases with helix angle) that requires thrust bearings for gear shaft. Double helical is more costly but avoids end thrust. Herringbone is similar to double helical but has no space separating the two opposed sets of teeth. It is harder to manufacture to high accuracies. Both herringbone and double helical stand up well for long periods under heavy load.



VARIATIONS IN CYCLOIDAL DESIGNS

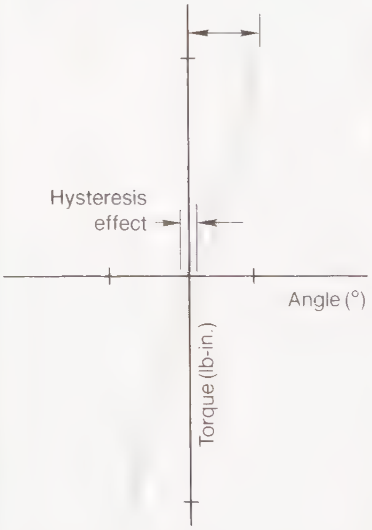


A four-gear differential schematic represents a variety of trochoidal drives. The epitrochoidal roller chains B and D are often concentric with the input-output (I/O) shafts. For a reducer where only the pitch circle for D is concentric with the I/O shafts, letting A = 18, B = C = 19, and D = 20 defines a reduction ratio of 10. Reductions to 80:1 are possible in similar volumes. A negative ratio means the output turns opposite the input.

CYCLOIDAL REDUCERS: Cycloidal speed reducers differ from most others in that they do not use gears to transmit motion. One manufacturer described the cycloidal hub as a circular disc with a sine wave ground onto its circumference. The advantage of the design is that all contacting internal surfaces roll against each other rather than slide, as with gear teeth.

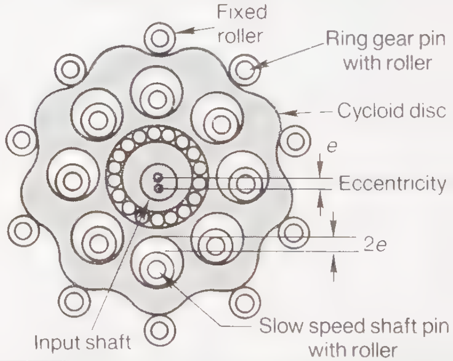
Generally, a cycloidal reducer has three major moving parts: a high-speed input shaft with mounted eccentric bearing assembly, cycloid disc, and a low-speed shaft assembly. Speed is reduced through the eccentric motion of the cycloid discs. For each complete revolution of the high-speed shaft, the discs advance one 'tooth' in the opposite direction. Two-disc systems improve torque capacity over one-disc models, and provide a nearly vibration-free drive.

HOW TO MEASURE STIFFNESS

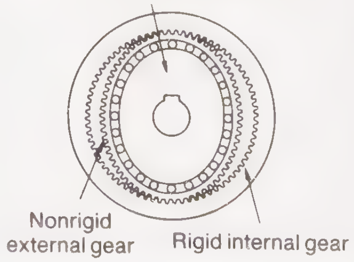


Stiffness in a reducer is usually measured by locking the input shaft and plotting torque vs. rotation on the output shaft. The slope of the trace is stiffness, in this case, about 574,000 lb-in./rad for the model tested. Absence of a "knee" in the curve as torque direction changes indicates low backlash.

INSIDE A CYCLOIDAL REDUCER



Elliptical ball-bearing assembly induces a traveling "wave" of mesh between gears



Heavy duty designs handle high-power and shock loads up to 500% of design load. Horizontal and vertical-mount units are available with oil lubrication or maintenance-free grease. Single and double-reduction units typically have ratios from 6 to over 7,000. Units handle input power from fractional to over 200 hp and torque to over 500,000 lb-in.

Medium-duty cycloidal reducers sometimes substitute a roller chain for the cam followers in a trochoidal drive. Here, a double-link chain wraps around a sprocket, and an epitrochoidal wheel turns inside the formed chain circle. Most often, two epitrochoidal planet wheels are used, each turning within a chain circle that has one or two more links than the number of lobes in the corresponding wheel of the compound planet. The arrangement allows almost any reduction ratio.

Robotic applications, such as reducing a servomotor output, requires zero backlash and high stiffness. In single reduction units, these features can be combined in a compact size. Some pancake-sized units have a thickness about one-third their diameter. Typical ratings are to 25,000 lb-in., and ratios to about 250:1. Input speeds for the smaller models reach 8,000 rpm.

BASE-MOUNTED REDUCERS

Base-mounted reducers are classified according to input speed. Industry normally considers low speed to be from 400 to 1,750 rpm (although many reducers must operate slower than this), medium speed from 1,750 to 3,600 rpm, and high speed from 3,600 to 20,000 rpm. Some reducers operate up to 70,000 rpm, but anything above 20,000 rpm is normally considered to be a nonstandard item.

Reducers use just about every commercial type of gear and all common shaft alignments. They may use single reduction or gear trains with numerous meshing gears.

Ratings

- Mechanical power is based on wear (durability) and strength (load) capacity and computed according to AGMA standards. Based on uniform load and negligible torque pulsations.
- Thermal power is the average power that can be transmitted continuously without overheating at normal ambient temperature and without special cooling. This rating varies with speed and ratio. Most AGMA ratings are based on a 100°F temperature rise above ambient with a maximum operating temperature of 200°F. In high ambient environments, a reducer's true thermal capacity is lower than indicated by catalog rating.

With most reducers, no auxiliary cooling is furnished but is available as optional equipment. The most common application where auxiliary cooling is needed is where gears operate at low ratios and high speeds. Specialized drives such as marine gears and pump drives often incorporate cooling equipment as part of the reducer.

Thermal rating, in addition to being affected by size of the housing, operating speed, and ambient temperature, is also determined by the amount of air circulating around the housing and by heating from direct sunlight or nearby hot equipment. Coatings of dust or dirt act as insulation and lower the thermal capacity of a reducer.

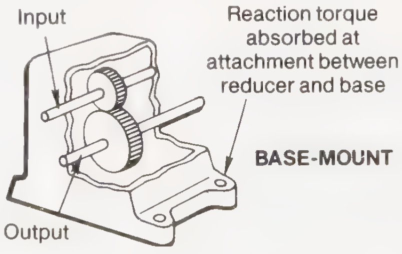
- Torque is based on speed and mechanical power ratings and is normally given as output torque.
- Overhung load is based on shaft bending stress and attendant bearing life; generally varies with ratio and speed. When catalog overhung-load ratings must be exceeded, an outboard bearing support is used to relieve the load on the shaft.

Specifications

- Service factor is a type of safety factor applied to the nominal power to be transmitted, thus, minimizing chances that the reducer will wear out too soon. Service factor is usually selected with consideration of maximum power of the prime mover, duty cycle, whether the reducer is operated continuously or intermittently, and whether there may be significant shock or overload. Service factor should be generous, especially with high-speed reducers.

AGMA has developed tables classifying speed-reducer loads according to severity (uniform, moderate shock, or heavy shock). Tables of service factors match these load classifications against operating hours per day and the type of prime mover. These tables are published in appropriate standards.

- Power ratings are usually determined by dividing the transmitted or rated power by the efficiency. Where there is uncertainty, the rated power of the prime mover is used with an appropriate service factor. The power of the prime move and capacity of the reducer normally should be the same; reserve motor capacity should not be provided unless the reducer has equivalent reserve.
- Torsional vibration is the torque variation from either power or load pulsations. Pumps and compressors do not load a reducer smoothly, and engines do not supply smooth input power. So a speed reducer is often subjected to severe torsional vibration. At resonant frequencies, the vibration is extremely dangerous to gears. All gear warranties and AGMA standards specifically exempt torsional vibration from performance ratings. Limits generally acceptable for normal ratings are vibratory torque not to exceed 25% of rated transmitted torque, and no torque reversal (tooth separation) at operating speed.

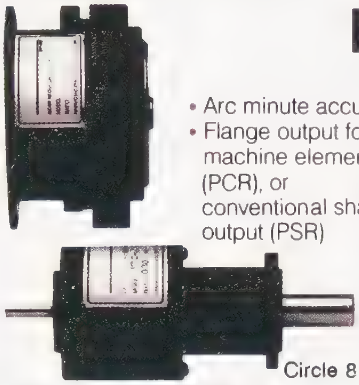

Input
Reaction torque absorbed at attachment between reducer and base
BASE-MOUNT
Output

Suitable for any application but especially well suited to heavy loads and high-speed drives.

- Lateral vibration is shaft motion from bearing deflection or produced as the shaft whirls at its critical frequency. Gear drives are normally designed to operate below the first flexural critical speed. And the first critical mode is normally the only one that must be avoided. However, some high-speed drives operate above the first, second, or even third critical speed.
- Axial thrust usually results from improper design but sometimes is a consequence of the type of load transmitted. Catalogs usually list an allowable value for axial thrust. Unintentional axial thrust most commonly arises from misaligned shafts, overloaded couplings, or poorly lubricated couplings. If the catalog does not list thrust load capacity, do not assume that the reducer can carry thrust loads.

HARMONIC DRIVE PRECISION... AND SHOCK LOAD PERFORMANCE

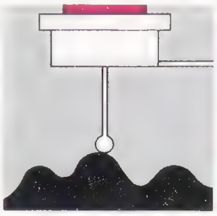
versatile, compact, low- or zero-backlash, high-ratio speed reduction and differential drive systems



PCR & PSR

Compact Reducers

- Arc minute accuracy
- Flange output for direct mounting to machine elements (PCR), or conventional shaft output (PSR)

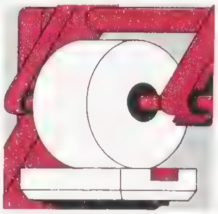


Circle 813

ISR

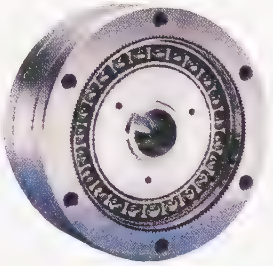
Industrial Speed Reducers

- Heavy-duty, industrial grade



- For high-ratio foot-mount, face-mount, and close-couple designs

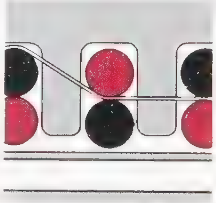
Circle 817



HDB

Phasing Differential Gear Sets

- For dynamic registration of rotating elements
- 1:1 differential transfers high-power driving torque. High trim ratios for precise low-power tuning.
- For high-speed automated trim and/or low-speed manual trim
- Compact for end-of-roll mounting



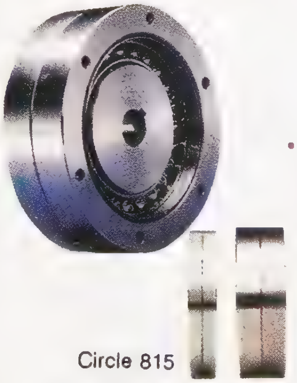
Circle 814

Infinit-Indexer®

Phase Adjusters

- For precise manual adjustment or registration
- Adjusts position of cams, cutoff knives, gears, etc.
- Zero backlash 100:1 speed reduction between adjusting ring and shaft or hub
- Secure locking for high torque loads

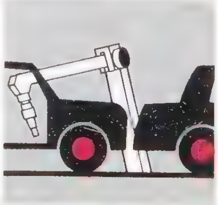
Circle 818



HDF & HDR

Pancake Component Gear Sets

- The most compact, single-stage, high-ratio gearing available
  - Low backlash
  - Light- and heavy-duty models for compactness or high load capacity

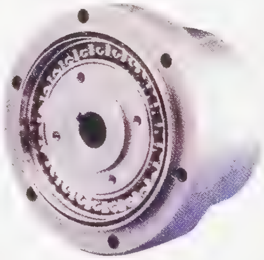


Circle 815

HDC

Low and Zero Backlash Component Gear Sets

- Highest torque-to-weight ratio
- Arc minute accuracy
- 50:1 to 320:1 ratios
- Up to 90% efficient; can be backdriven



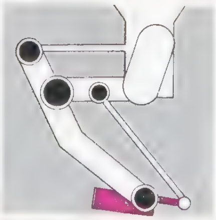
Circle 819

RV-A II

Rotary Vector Drive

The advantages of Harmonic Drive plus:

- Shock resistance 5 times rated torque
- Exceptional torsional rigidity



Circle 816

Harmonic Drive™ TECHNOLOGIES

Teijin Seiki Boston, Inc.
247 Lynnfield Street
Peabody, MA 01960
TEL: (508) 532-1800
FAX: (508) 532-9406

The Advantages of Harmonic Drive Gearing

Because it consists of only three simple parts, Harmonic Drive gearing offers design engineers the freedom to integrate drive components directly into machines or equipment. Harmonic Drive is a pure torque couple with all concentric elements and requires less space and less bulky support structures than conventional gearing.

Harmonic Drive's precision and performance are ideal in applications requiring accurate positioning or precise motion control.

Low or Zero Backlash

Natural gear preload and almost pure radial tooth engagement allow standard Harmonic Drive gearing to operate with essentially zero backlash for the entire gear life without preload adjustments or significant wear.

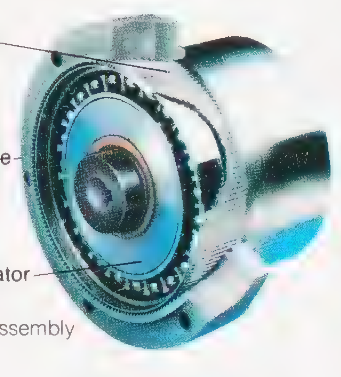
Efficiencies as High as 90%

Measured on actual shaft-to-shaft losses rather than tooth losses (as with other gearing), standard Harmonic Drive gearing efficiencies are normally in the 80 – 90% range.

Simple Support Requirements

Since torque is transmitted by pure couple, Harmonic Drive gearing does not generate radial loads and, therefore, can be used with much simpler bearings and less structural support than other forms of gearing.

HDC CUP COMPONENT GEAR SET



Flexspline
An elliptical, nonrigid, external gear

Circular Spline
A round, rigid, internal gear

Wave Generator
An elliptical ball bearing assembly

High Single-Stage Ratios From 50:1 Up

Depending on size, Harmonic Drive products offer ratios from 50:1 (60:1 for standard products) to as high as 320:1. Using compound drives, much higher ratios can be achieved.

Torque Equal to Drives Twice as Large

Pound for pound, no other mechanical power transmission can compare with Harmonic Drive gearing for torque capacity.

Excellent Positional Accuracy and Repeatability

Harmonic Drive gearing's design ensures that approximately 10% of the total teeth are engaged at any point in time, minimizing the effect of tooth-to-tooth error. Accuracies as fine as 30 arc seconds are achievable in some sizes. Repeatabilities are in the arc second range.

Design Flexibility

Harmonic Drive gearing allows designers multiple input/output possibilities in speed reduction and speed increasing applications. Concentric shafting makes it ideal for differential designs.

Long Life and High Reliability

Proven in years of industrial, military, and other applications, Harmonic Drive gearing has an average life of over 15,000 hours at rated loads. In addition, the tooth mesh is unaffected by the impact of stepping motors or frequent starts, stops, and reversals.

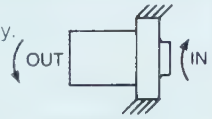
Additional Advantages of RV-A II Gear

- Shock resistance 5 times rated torque
- Exceptional torsional rigidity

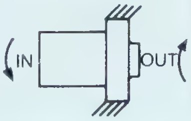
The Rotary Vector Drive is rapidly gaining preference worldwide as the premier transmission for use in robotics applications. Rotary Vector Drives are available in ratios from 30:1 to 185:1 with output torque ratings from 500 to 33,000 in.-lbs.

Input/Output Versatility

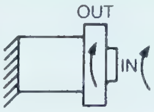
1\.
Speed Reducer:
Circular Spline stationary. Wave Generator input. Flexspline output. Ratio as tabulated.



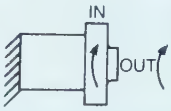
2\.
Speed Increaser:
Circular Spline stationary. Flexspline input. Wave Generator output. Ratio as tabulated.



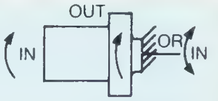
3\.
Speed Reducer:
Flexspline stationary. Wave Generator input. Circular Spline output. Ratio as tabulated plus 1.



4\.
Speed Increaser:
Flexspline stationary. Circular Spline input. Wave Generator output. Ratio as tabulated plus 1.

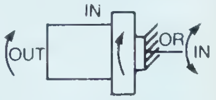


5\.
Speed Reducer/ Differential: Wave Generator stationary. Flexspline input. Circular Spline output.



$$\text{Ratio} = \frac{\text{Tabulated Ratio}}{\text{Tabulated Ratio} + 1}$$

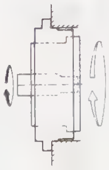
6\.
Speed Increaser/ Differential: Wave Generator stationary. Circular Spline input. Flexspline output.



$$\text{Ratio} = \frac{\text{Tabulated Ratio} + 1}{\text{Tabulated Ratio}}$$

Rotary Direction and Speed Ratio

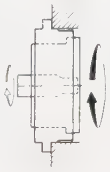
1\.
Reduction gear



Input: Input gear
Output: Shaft
Rigid: Case

$i = \frac{1}{R}$

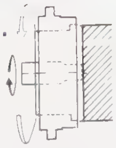
2\.
Speed increasing gear



Input: Shaft
Output Input gear
Rigid: Case

$i = R$

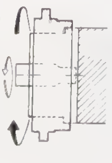
3\.



Input: Input gear
Output: Case
Rigid: Shaft

$i = -\frac{1}{R-1}$

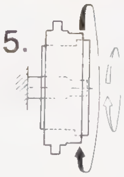
4\.



Input: Case
Output. Input gear
Rigid: Shaft

$i = -(R-1)$

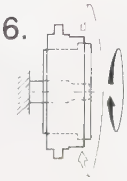
5\.



Input: Case
Output: Shaft
Rigid: Input gear

$i = \frac{R-1}{R}$

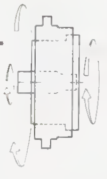
6\.



Input: Shaft
Output: Case
Rigid: Input gear

$i = \frac{R}{R-1}$

7\.



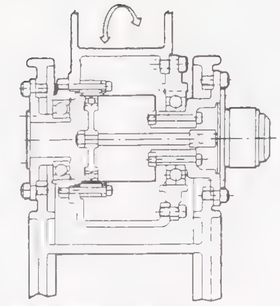
In case all the components in rotating motion, the applicable combinations are as illustrated in 1 through 6 above. This mechanism can be used also as variable speed gear

- The symbol "*i*" indicates a speed ratio of the input to the output The sign "—" in above equation means the output shaft rotates to the reverse direction of the input shaft
- The symbol "R" is shown in the Rating Table.

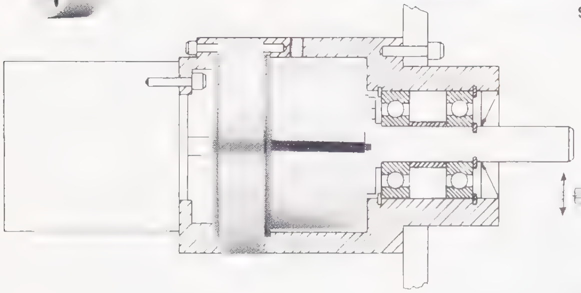
$$(R = 1 + \frac{Z_2}{Z_1} \cdot Z_4)$$

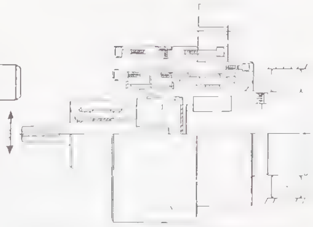
HDC Cup Component Gear Sets

With tremendous configuration versatility, Harmonic Drive HDC Cup and HDF Pancake Component Gear Sets solve a wide range of motion control problems. Some typical applications are shown here



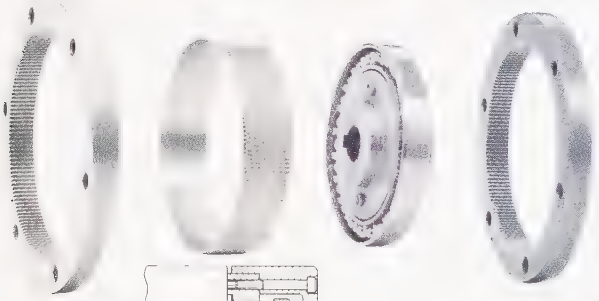
TYPICAL ROBOT JOINTS:
SHOULDER, ELBOW AND WRIST

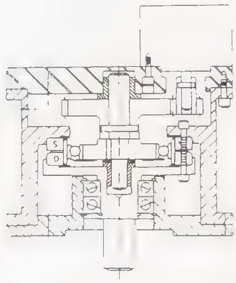




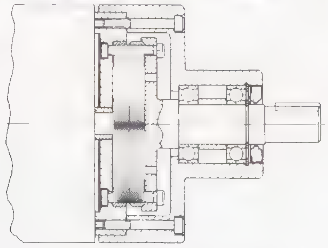
DIFFERENTIAL PHASE CONTROL DRIVE

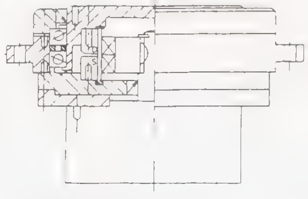
HDF Pancake Component Gear Sets





PRESTAGED PANCAKE ACTUATOR





ROTARY INDEX TABLE

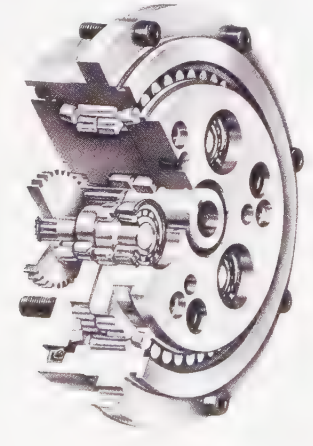
Torque Ratings[1]

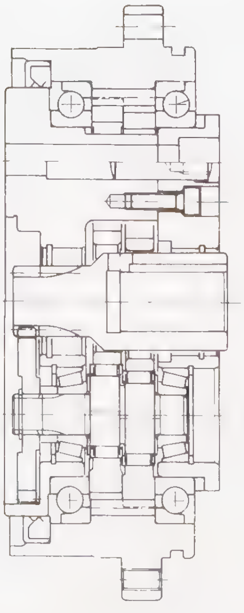
HDC, ISR[5], PCR[6], PSR[7], HDR[8]

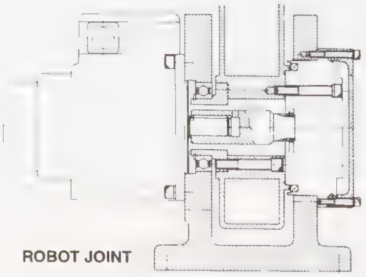
		OUTPUT TORQUE			
		@1750 RPM INPUT		MAXIMUM[2]	
SIZE	RATIO[3]	lb-in	Nm	lb-in	Nm
10	60	30	3.4	30	3.4
	80	40	4.5	40	4.5
1C	60	102	11.5	119	13.4
	72	102	11.5	119	13.4
	80	102	11.5	140	15.8
	100	102	11.5	180*	20.3*
3C	60	355	40.1	470	53.1
	80	355	40.1	470	53.1
	100	375	42.4	690	78.0
	120	375	42.4	900	101.7
	140	375	42.4	1,120*	126.6*
	160	375	42.4	1.120*	126.6*
5C	60	620	70.1	830	93.8
	80	620	70.1	830	93.8
	100	620	70.1	1,240	140.1
	120	620	70.1	1,690	191.0
	140	620	70.1	1,900	214.7*
	160	620	70.1	1,700	192.1*
	180	620	70.1	1,580*	178.5*
	200	620	70.1	1,580*	178.5*
1M	60	1,245	140.7	1,830	206.8
	80	1,245	140.7	1,830	206.8
	100	1,245	140.7	2,640	298.3
	120	1,245	140.7	3,410	385.3
	140	1,245	140.7	4,700*	531.1*
	160	1,245	140.7	4,700*	531.1*
	180	1,245	140.7	4,000*	452.0*
	200	1.245	140.7	4.000*	452.0*

RV-A II Gearing

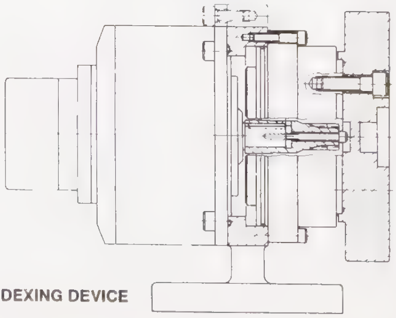
Drive versatility plus high shock load capability make RV-A II drives ideal for many applications.







ROBOT JOINT



INDEXING DEVICE

SIZE	RATIO[3]	OUTPUT TORQUE @1750 RPM INPUT lb-in	OUTPUT TORQUE @1750 RPM INPUT Nm	OUTPUT TORQUE MAXIMUM[2] lb-in	OUTPUT TORQUE MAXIMUM[2] Nm
2M	60	2,075	234.5	2,760	311.9
	80	2,075	234.5	2,760	311.9
	100	2,610	294.9	4,070	459.9
	120	2,610	294.9	5,060	571.8
	140	2,610	294.9	6,130	692.7
	160	2,610	294.9	7,200	813.6
	180	2,610	294.9	6,600*	745.8*
	200	2,610	294.9	6,600*	745.8*
4M	60	3,890	439.6	5,110	577.4
	80	3,890	439.6	5,110	577.4
	100	4,860	549.2	6,500	734.5
	120	4,860	549.2	9,500	1073.5
	140	4,860	549.2	11,200	1265.6
	160	4,860	549.2	13,100	1480.3
	180	4,860	549.2	15,500*	1751.5*
	200	4,860	549.2	15,500*	1751.5*
8M	60	7,885	891.0	10,200	1152.6
	80	7,885	891.0	10,200	1152.6
	100	9,010	1018.1	15,300	1728.9
	120	9,010	1018.1	19,300	2180.9
	140	9,010	1018.1	23,000	2599.0
	160	9,010	1018.1	26,600	3005.8
	180	9,010	1018.1	24,000*	2712.0*
	200	9,010	1018.1	24,000*	2712.0*
15M	60	13,715	1549.8	18,200	2056.6
	80	13,715	1549.8	18,200	2056.6
	100	17,780	2009.1	26,000	2938.0
	120	17,780	2009.1	33,600	3976.8
	140	17,780	2009.1	40,800	4610.4
	160	17,780	2009.1	47,900	5412.7
	180	17,780	2009.1	50,000*	5650.0*
	200	17,780	2009.1	50,000*	5650.0*

Torque Ratings[1]

HDF[4], HDB

SIZE	RATIO[3]	OUTPUT TORQUE @1750 RPM INPUT lb-in	OUTPUT TORQUE @1750 RPM INPUT Nm	OUTPUT TORQUE MAXIMUM[2] lb-in	OUTPUT TORQUE MAXIMUM[2] Nm
14	80	56	6	90	10
	100	56	6	90	10
	110	56	6	90	10
20	80	246	28	250	28
	100	246	28	300	34
	120	246	28	350	40
	160	246	28	390	44
25	80	406	46	425	48
	100	406	46	600	68
	120	406	46	700	79
	160	406	46	780	88
32	80	810	92	950	107
	100	810	92	1200	136
	120	810	92	1400	158
	160	810	92	1550	175
40	80	1705	193	1700	192
	100	1705	193	2400	271
	120	1705	193	2700	305
	160	1705	193	3100	350
50	80	3180	359	3100	350
	100	3180	359	4200	475
	120	3180	359	5200	588
	160	3180	359	5800	655

NOTES:

1) Output Torque ratings are based on an L-10 Life of 3000 hours.
2) Repetitive momentary or continuous running load not to exceed Maximum Output Torque rating.
3) Bold face indicates standard ratios.
4) Consult factory for special high ratios up to approximately 40,000:1.
5) Available in sizes 3C, 5C, 1M, 2M, 4M, 8M
6) Available in sizes 3C, 5C, 1M
7) Available in sizes 10, 1C
8) Available in sizes comparable to 3C, 5C, 1M, 2M, 4M, 8M

*Denotes Maximum Torque output limited by ratcheting.

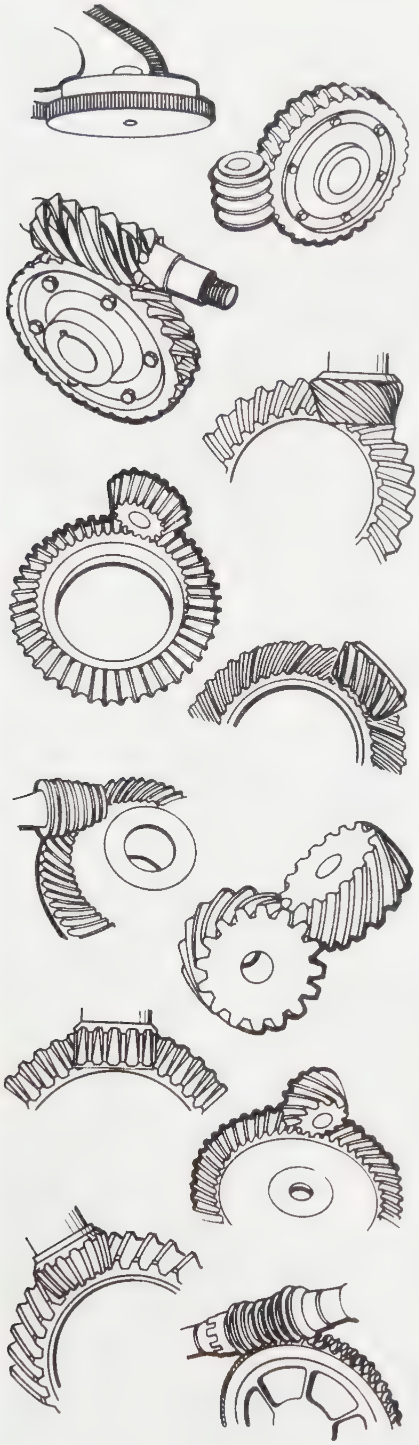
Torque Ratings[9]

MODEL	RATIO RANGE	OUTPUT TORQUE RATED AT 15 RPM OUTPUT lb - in	OUTPUT TORQUE RATED AT 15 RPM OUTPUT Nm	OUTPUT TORQUE MAXIMUM SHOCK LOAD lb - in	OUTPUT TORQUE MAXIMUM SHOCK LOAD Nm
RV-6A II	30-103	520[10]	59[10]	2,600[10]	294[10]
RV-15A II	57-121	1,212	137	6,060	685
RV-30A II	57-153	2,947	333	14,735	1,665
RV-60A II	57-153	5,637	637	28,185	3,185
RV-135A II	66-171	11,708	1,323	58,540	6,615
RV-250A II	66-185	21,681	2,450	108,405	12,250
RV-380A II	66-192	32,955	3,724	164,755	18,620

9) Output Torque ratings are based on an L-10 Life of 6000 hours.
10) Torque ratings are based on 30 RPM output.

Harmonic Drive™
TECHNOLOGIES

Teijin Seiki Boston, Inc.
247 Lynnfield Street
Peabody, MA 01960
TEL: (508) 532-1800
FAX: (508) 532-9406



GEARS WITH INTERSECTING OR SKEWED SHAFTS

Beveloid: Proprietary. Provides accurate motion not affected by mounting errors or variation. Low load capacity. Can be used at zero backlash. Often used in precision instruments. Commonly used for intersecting axis gears but also suitable for parallel and skewed axes. High cost is a possible drawback.

Worm: Provides maximum reduction ratios for a given center distance. Quiet and smooth action. Used only for speed reduction. Generally cannot back-drive at ratios greater than about 20:1. Contact area is large, thus load capacity is high in spite of sliding action. Shafts are almost always at right angles.

Cavex worm: A proprietary gear with concave worm-thread meshing with convex gear tooth. Provides for lower tooth contact stress and better lubrication.

Hypoid: Similar to spiral-bevel gears except that shafts do not intersect. Also operates more smoothly and more quietly and is stronger for a given ratio. Because shafts do not intersect, bearings can be mounted on both sides for high rigidity. Permit very high drive ratios. Shaft angles usually 90°, but other angles are possible. Has higher load capacity than same size and ratio spiral bevel gear.

Straight bevel: The simplest type of gear for intersecting shafts. Commonly used on shafts intersecting at right angles, but can be used on shafts meeting at any angle. Designed in pairs, thus are not always interchangeable. Supporting shafts and bearings must be rigid to maintain proper tooth contact.

Spiral bevel: Carry higher loads and run more quietly than straight bevel gears. But are more expensive and have greater thrust loads. Because teeth are at an angle to the axis of rotation, loading may be distributed over two or more teeth at any instant, depending on spiral angle.

Spiroid: Proprietary. Tapered pinions mesh with face-type gear. Line contact across full face provides high load capacity.

Crossed helical: Also known as spiral gears. Similar in appearance to conventional helical gears. Low load capacity because of low tooth-contact area. Principally used to provide a wide variety of speed ratios without change in center distance or gear size. Can be used with nonintersecting, nonparallel shafts.

Face: Similar to bevel gears, but mates with spur or helical pinions. Mounting of the pinion is not critical as it is with bevel gears. Also can be used with skewed shafts. Load capacity is less than same size straight bevel gear.

Helicon: Proprietary. Special thread form on cylindrical pinion meshes with face gear. Load-carrying capability similar to spiroid. Well adapted to mass production because tooth form is easily cast or molded in correct form.

Zerol: Similar to spiral bevel but with teeth arranged so that thrust loads are equivalent to those of straight bevel.

Cone drive: A proprietary type where worm shape resembles an hourglass and has double-enveloping thread to increase total contact area, thus increasing load capacity.

boxes require special care in design and manufacturing. They often involve high speeds which may create problems in gear dynamics. Also, frictional and drag forces are magnified.

Metal chain drives

Metal-chain drives are normally used for applications below 3,000 rpm where accuracy and reliability must be greater than that provided by rubber belts. Because a metal chain does not stretch or slip as a belt does, chain drives maintain constant speed ratios under widely varying load conditions and need only infrequent adjustment.

Reliability of a chain drive is superior to that of belts, with chain service life typically rated at 10,000 h, which is about three to four times longer than that of belts. Also, chain drives generally are more compact than similarly rated belt drives. For example, a 10-hp chain drive is about 50% smaller than a comparable belt drive.

Chains can be replaced more easily than belts because sheave adjustment is not changed for the replacement. Chains can be removed by simply pulling out a master pin in the link and threading the new chain through the drives. But because chain drives do not slip, they cannot provide the overload and jam protection of belt drives. Also, the heavy weight of metal chain compared to light rubber belts produces penalties in efficiency, cost, and response time. Efficiency for chain drives — about 85 to 90% — is slightly less than that of conventional belt drives. And chain drives cost about 20 to 50% more than belt drives, with prices ranging from about $300 to $10,000 for 0.70 to 100-hp models.

There are two basic types of links in chain drives: self-forming teeth and extended pin. Self-forming teeth have slats that extend on each side of the link and conform to the ribbed sides of the sheave faces for a positive engagement. This type usually transmits up to 25 hp and operates at input speeds to almost 900 rpm. The extended-pin type, with pins projecting on both sides of the link to engage the sheave face, transmits from 7.5 to 100 hp at input

DESIGNING CHAIN DRIVES

Ratings of most power chains are based on a life of 15,000 to 20,000 h with correct alignment, lubrication, and maintenance. These optimum conditions rarely exist in practice, so generous service factors, as high as 1.7, are often must be applied where heavy shock loading is anticipated.

For heavy load and low speed, massive (and relatively low strength) chain can often be used because centrifugal force is not a limiting factor. At high speed and light load, a light chain is usually optimum. For heavy load and high speed, either roller or silent chain normally is required to provide maximum strength per pound.

Sprockets are covered by ANSI standards. Various types of sprockets are available including cast, powdered metal, flame-cut plate, machined and plastic materials.

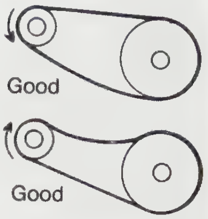
Cast sprockets are generally used where precision operation is not required, as with detachable, pintle, and offset sidebar chain. Torch-cut sprockets can be used with nonprecision chains operating at low speeds. At low speeds, even roller chain can sometimes be operated on cast sprockets, although this can shorten service life.

Plastic sprockets do not have the load capacity of metal, but plastic often needs minimum lubrication and is widely used in food machinery where cleanliness is important. Powdered metal is increasingly used in high-power precision applications.

Many manufacturers offer special-purpose sprockets such as those incorporating shear pins, overload clutches, or other devices protecting against shock or overload. Selecting a large drive sprocket increases chain speed and, thus, permits the transmission of more power within the limits of starting torque and available space.

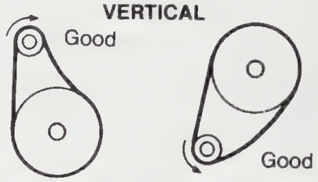
Speed ratios should not exceed 10:1 for roller or silent chain or 6:1 for other types. Chain wrap should be at least 120° on the smaller sprocket. Double reduction drives must be used if requirements cannot be met within these limitations.

HORIZONTAL



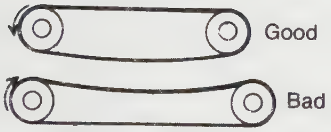
Preferred position for a chain drive places the shaft centers on a horizontal line or inclined not more than 45°. Slack strand may be on either the upper or lower side.

VERTICAL



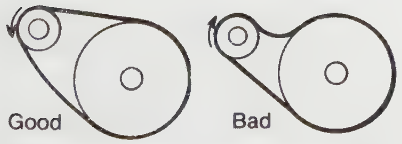
Vertical drives should be avoided if possible. They must run fairly taut, which requires frequent center-distance adjustment as the chain elongates. Less adjustment is required if the drive is positioned slightly off the vertical. Where a line between centers is more than 45° above the horizontal, slack should be in the strand with the lesser angle to horizontal.

LONG-CENTERS



Long-center-distance drives should have the slack strand on the bottom. Slack in the upper strand could cause the upper strand to hit the lower as the chain elongates.

SHORT-CENTERS



On short-center-distance drives, slack should be in the lower strand. Slack in the upper strand could force the chain out of engagement.

A sprocket undergoes load pulsations as individual links of the chain engage the teeth. Numerous small pulsations produce smoother operation than fewer heavy pulsations. Therefore, there are minimum limits on the number of sprocket teeth that can be used in a drive.

For roller chain operating at low speed, the smaller sprocket should have at least 12 to 17 teeth. At high speeds, it should have at least 25 teeth. Inverted-tooth sprockets can have as few as 17 teeth, but 19 or 21 teeth is the preferred minimum.

Other types of chain — which are not normally operated at speeds as high as roller or inverted-tooth types — can operate with as few as six teeth provided that speeds are low.

Ideally, drives should be designed so that sprockets are vertical (and the force of gravity does not tend to pull the chain off the centerline). The drive direction should be such to keep the upper span of chain in tension.

Sprocket center distance should exceed half the sum of the sprocket ODs to avoid tooth interference. A good rule is to have the center distance equal the diameter of the large sprocket plus half the diameter of the small sprocket. Such drives assure a wrap of 120° on the small sprocket.

The correct amount of sag in the slack span is important to limit catenary tension from the weight of the chain. So a drive should have provision for adjustment if at all possible. For maximum chain life, this sag should be 2 to 3% of the center distance.

speeds to 2,900 rpm. In the range of 7.5 to 25 hp, ratings for the two link types overlap, with prices comparable in the 7.5 to 15-hp range and with extended-pin units being less expensive in the 20 to 25-hp bracket.

Multi-Speed

These drives are used to provide a variable output speed from a constant-speed power source (as in a machine tool driven by a constant-speed ac motor) or to provide torque increase for a variable-speed power source (as in an automobile). Variable mechanical drives are less costly than competing electrical variable-speed drives, and the control of mechanical drives is much simpler. But mechanical drives often are not as durable and cannot be controlled as precisely as electrical drives. And except for gear drives, the mechanical type generally cannot transmit as much power as electrical drives if variable speed is essential.

The basic types of adjustable-speed drives are geared transmissions (which provide only specific fixed-speed ratios), variable-pitch belt and chain drives (which provide infinitely variable speeds), traction drives (also infinitely variable), and fluid drives.

Gear drives

The most durable, rugged, and efficient of all adjustable-speed drives, but capable of providing only a specific number of fixed gear ratios. Normally chosen for applications involving heavy loads or requiring long, trouble-free life. Generally, more expensive than belt or chain drives. Gear drives are commonly classified according to end use:

Automotive main transmissions: Used as main transmissions in cars, trucks, farm machinery, and earth-moving equipment. Usually provide from four to ten speeds.

Auxiliary transmissions: Usually installed behind the main transmission to increase available ratios.

Transfer cases: Provide additional power outlets (as in a four-wheel-drive vehicle) or provide offset from normal driveline angles.

Power takeoffs: Usually mounted beside main transmission and driven by an additional gear in that transmission. Basically similar to a transfer case.

Marine gears: Transmissions carrying power to the propeller on a marine drive. Differ from other transmissions in that they generally provide

VIBRATION ANALYSIS HELPS PINPOINT PROBLEM COMPONENTS

Spectrum measurement, something that dynamic signal analyzers do, is often used for vibration analysis. Low-level vibration produced during early stages of some defects cannot be detected by standard vibration meters. In effect, initial trouble signs are buried by larger residual imbalance components of the vibration. This is especially true of rolling-element bearings, and it makes troubleshooting them difficult.

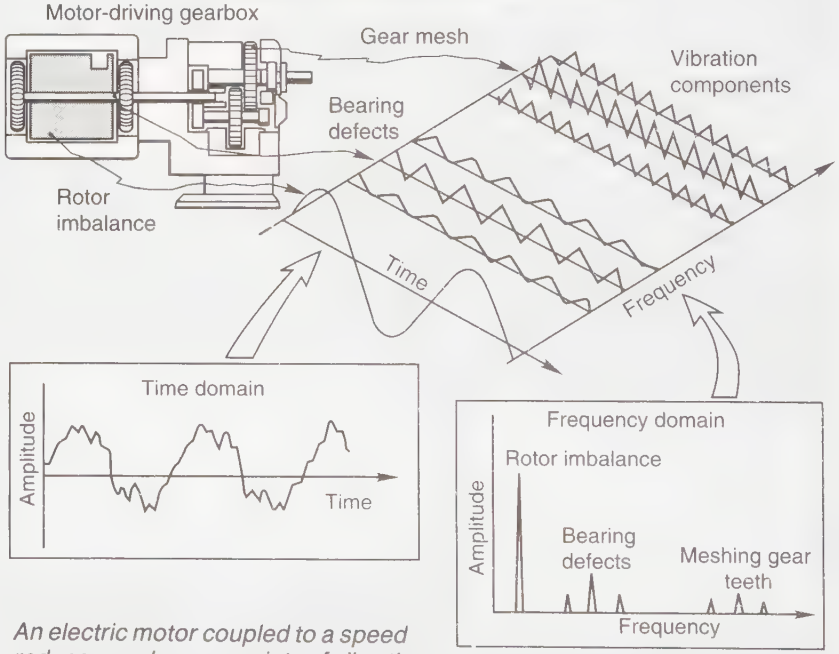
An advantage of frequency-domain analysis is that low-level signals are easily seen, even among signals 1,000 times larger. This is illustrated in the accompanying time-frequency domain display where low-level signals, readily apparent in the frequency domain, cannot be seen in the time domain. A key to this capability is the logarithmic display of amplitudes, expressed in decibels. Although linear (nonlogarithmic) display seems more natural to most people, logarithmic display assists early detection of defects.

One example where frequency-domain measurement pays big dividends is in machinery analysis. Here, internal vibration sources are rotor imbalance, ball-bearing defect, and reduction gear meshing. To simplify the example, sources of vibration are limited to a few types.

Imbalance produces a sinusoidal vibration at a frequency of once per revolution. Also, a single defect in the ball bearing's outer race produces an impulsive vibration each time a ball passes it - usually about four times per revolution. This is assumed to be a sine wave. The two lower amplitude sine waves around this frequency are caused by interaction (modulation) of the bearing defect force with the imbalance force. These signals are called sidebands, and occur often in machinery vibration. They are spaced at increments of plus and minus the running speed from the defect frequency.

The gear-mesh frequency appears at running speed times the number of teeth on the main-shaft gear. Mesh frequency is often set to 10 for simplicity. The running-speed sidebands around the gear-meshing frequency usually indicate eccentricity in the gear.

PINPOINTING WEARING COMPONENTS

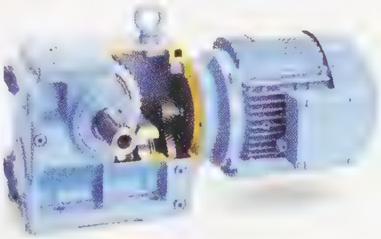


An electric motor coupled to a speed reducer produces a variety of vibration signals. The time domain presents a sum of vibration signals that is difficult to interpret. The frequency domain, however, makes diagnosing machine problem easier with more discrete frequencies and amplitudes.

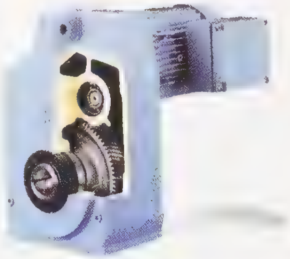
EURODRIVE
The Driving Force in Power Transmission

Constant Speed Drives

Right Angle (Helical-Bevel) Gearmotors & Speed Reducers
.33 to 340 HP. Output speeds available from 288 to 0.12 RPM. Output torques to 354,000 lb. in. 95% efficient. Circle 051

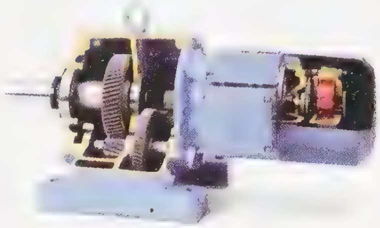


Right Angle (Helical-Worm) Gearmotors & Speed Reducers
.33 to 25 HP. Output speeds available from 244 to 0.12 RPM. Output torques to 35,400 lb. in. Up to 92% efficient. Circle 052



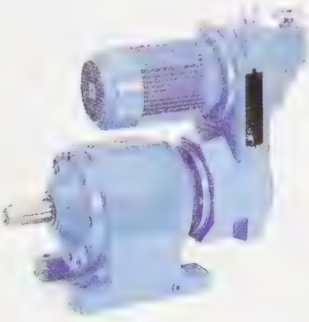
SNUGGLER® Shaft-Mounted (Helical) Gearmotors & Speed Reducers
.33 to 60 HP. Output speeds available from 180 to 0.12 RPM. Output torques to 53,100 lb. in. 96% efficient.
Circle 053

Polyphase Motors & Brakemotors
.33 to 60 HP. Corrosion resistant. Output speeds from 900 to 3600 RPM. 50 Hz or 60 Hz. Brakemotors feature: multiple cycles per minute, fast action and adjustable retarding torque. Available with brake torques to 440 ft. lbs.
Circle 054



Parallel (Helical) Gearmotors & Speed Reducers
.33 to 180 HP. Output speeds available from 1133 RPM to 0.06 RPM. Output torques to 141,600 lb. in. 94% efficient.
Circle 055

Adjustable Speed Drives



VARIGEAR® Belt-Type
High performance. Rugged and dependable. 1/2 to 60 HP. Up to 8:1 speed range. Output torques to 354,000 lb. in.
Circle 056

MOVITRAC® A-C Electrical
Advanced inverter design. Constant torque throughout entire speed range. Protected against shorts.

Circle 057

VARIMOT® Traction-Type
No fluids in traction case. Low cost. Compact. Long service life. Minimal maintenance. 1/2 to 15 HP. 4:1 or 5:1 speed range. Output torques to 354,000 lb. in.
Circle 058

SEW
EURODRIVE

SOUTHEAST MANUFACTURING & ASSEMBLY CENTER
1275 Old Spartanburg Hwy./Lyman, SC 29365
(803) 439-7537/Telex: 80-5550

MIDWEST ASSEMBLY CENTER
2001 West Main Street/Troy, OH 45373
(513) 335-0036/Telex: 687-4204

WEST COAST ASSEMBLY CENTER
30599 San Antonio Road/Hayward, CA 94544
(415) 487-3560/Telex: 17-2268

EAST COAST ASSEMBLY CENTER
200 High Hill Road/Bridgeport, NJ 08014
(609) 467-2277

SOUTHWEST ASSEMBLY CENTER
3950 Platinum Way/Dallas, TX 75237
(214) 330-4824

single forward and reverse speeds and use friction-type shifting clutches.

Hydraulic drives: Gear boxes connecting power source and hydraulic pumps in hydrostatic drives.

Industrial transmissions: A broad category applying to any transmission powering machinery other than that described above. Many have integral power packages, such as electric or hydraulic motors, or they may be an integral part of driven components.

Differentials: A differential is a set of gears with three independent, rotating members, with a speed and torque relationship to each other. This definition creates two application types.

The first consists of one input and two outputs. The automobile differential is the best example here. The important factor in this type of application is that the two outputs are connected mechanically. In the automobile, the connection is the road. The differential automatically balances speeds and torques between the two wheels because only the sum of the wheel speeds is defined by the input speed. That means that each wheel will rotate at the speed required to maintain the predetermined torque relationship of 1:1 between them.

The second application type has two inputs and one output. Less well known than the first, this technique solves industrial problems when the superimposition of one motion relative to another is required; such as timing of cutoff, registration control on printing presses, tension control, and phase shifting in the textile industry.

Differential efficiency is a function of the relative speed of the three elements. As relative speeds increase, the inherent losses due to basic gear efficiency, seals, and bearings also increase; thus, efficiency decreases.

Vehicle transmission

Automatic and manual vehicle transmissions have always been competitive with each other. While this is still true, each has found its niche in truck and bus markets.

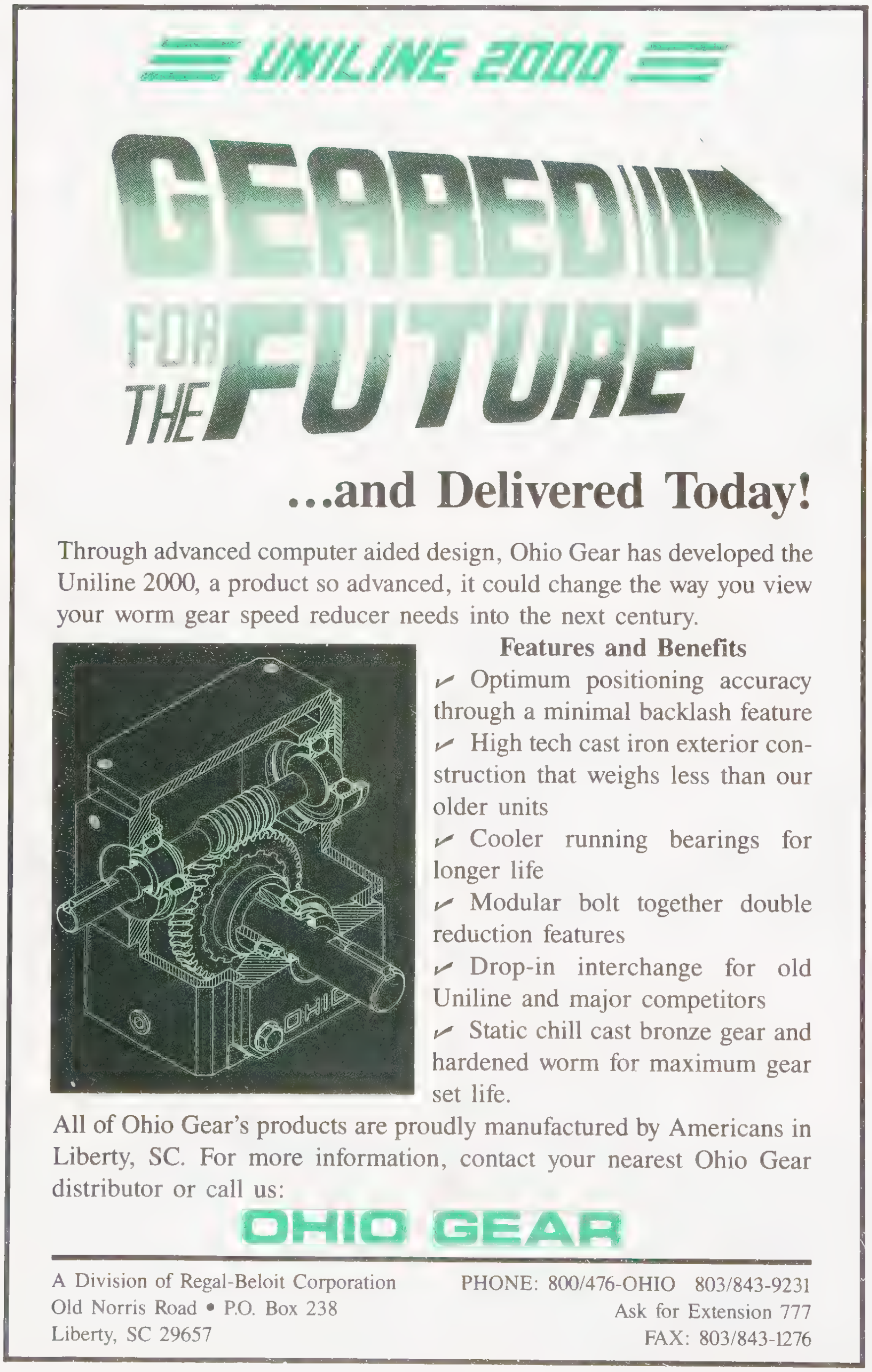
Advantages of manual over automatic transmissions are one-third to one-fourth lower cost, lower weight, and a greater number of forward speeds. This is offset somewhat by greater driver skill requirements. Payoff is higher fuel economy because the clutch provides lock-up with each engagement.

Manual transmissions: Recent advances here include shorter lever throws that require less effort. Gears have increased contact ratio, are smaller, and are hard finished to reduce operating weight and noise. Weight is further reduced, in some cases, with aluminum housings.

A new assembly technique called end-case loading simplifies maintenance and rebuilding. It allows assembly of components and gears with the transmission on end and outside the case. The housing is then lowered over the assembly to hold everything together.

Another new concept is twin layshafts. Torque is transmitted to gear shafts, or layshafts, on parallel fixed axes. Twin layshafts in 10 and 16-speed transmissions allow more teeth in simultaneous contact for smooth power flow. Other advantages are reduced bearing loads by balancing axial and radial gear forces and reduced noise with better tooth contact mesh.

Automatic transmissions: Generally, these have defined their role as assistants to less-skilled drivers. Even though they may cost more than similarly sized manuals, the higher cost is



...and Delivered Today!

Through advanced computer aided design, Ohio Gear has developed the Uniline 2000, a product so advanced, it could change the way you view your worm gear speed reducer needs into the next century.

Features and Benefits

- ✓ Optimum positioning accuracy through a minimal backlash feature
- ✓ High tech cast iron exterior construction that weighs less than our older units
- ✓ Cooler running bearings for longer life
- ✓ Modular bolt together double reduction features
- ✓ Drop-in interchange for old Uniline and major competitors
- ✓ Static chill cast bronze gear and hardened worm for maximum gear set life.

All of Ohio Gear's products are proudly manufactured by Americans in Liberty, SC. For more information, contact your nearest Ohio Gear distributor or call us:

OHIO GEAR

A Division of Regal-Beloit Corporation
Old Norris Road • P.O. Box 238
Liberty, SC 29657

PHONE: 800/476-OHIO 803/843-9231
Ask for Extension 777
FAX: 803/843-1276

Circle 238

offset by operating simplicity, easier driver training, and improved road safety. In addition, some bus fleet maintenance supervisors report that overall fuel economy actually increases 2 to 3% when automatics replace manuals.

Typically, these transmissions are hydraulically controlled; thus, their operation can be optimized with electrohydraulic controls that accept instructions from on-board computers. Electronic transmission controls typically use PROMs that contain the program for transmission functions. Programmability then allows a school bus transmission to operate differently than an identical one in a rural delivery truck. More often now, closed-loop algorithms are governing transmission functions for greater efficiency.

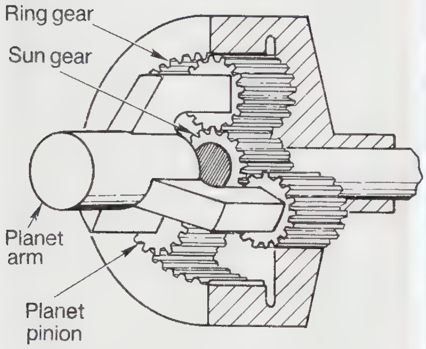
Other automatic transmission developments include retarders, torque converters that lock-up. Retarders act like an internal brake to dissipate vehicle speed through a fluid coupling-type rotor and oil-cooled friction clutch packs. Retarders can operate from the brake pedal, a separate foot pedal, or a selector lever on the dashboard. Advantages are reduced brake maintenance, and improved vehicle control in severe or long downhill conditions.

Torque converter lock-up is programmed for upshifting from second gear and higher. This simple feature allows automatics to mimic manual transmissions by eliminating torque converter slip common to earlier designs.

Multispeed transmissions have intrigued vehicle manufacturers with their promise of greater fuel economy. One of the latest developments in this area is a continuously variable transmission with a steel belt operating on variable sheaves. Intended for auto applications, the drive has teased automakers for a number of years but so far has proven useful only in low-power or stationary applications.

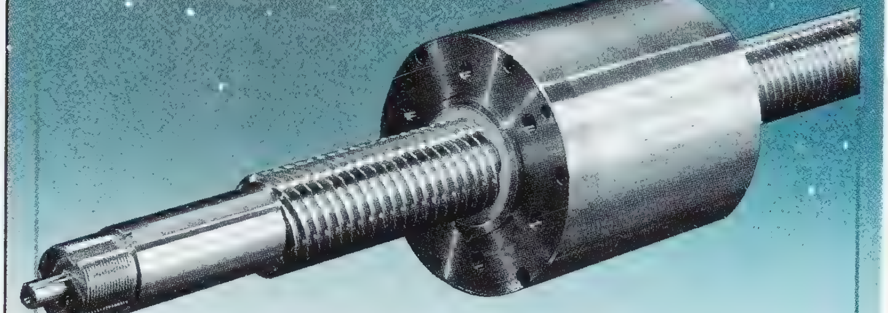
A transmission with many speeds, or increments, can approximate a continuously variable device. With a high initial ratio, the torque converter can be replaced with a simpler clutch. Computer control can maintain engine speed to avoid torque/speed points that produce the worst emissions. Most

PLANETARY DIFFERENTIAL GEARING

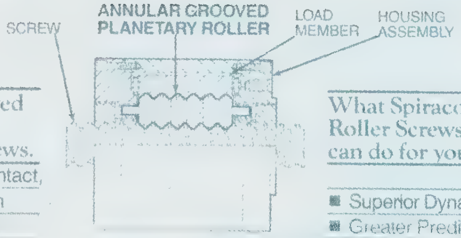


Planetary gear drives consist of three stages: a central sun gear; three to five planet gears mounted on planet arms and rotating around the sun gear; and a ring gear surrounding all the other gears and engaging the planets. The input, output, and auxiliary terminals in a different system can be connected to any of these stages to produce the required speed and power relationships.

An Advance of Planetary Importance



SPIRACON®
Planetary Roller Screws



What annular grooved rollers do for Spiracon Roller Screws.

They provide full line contact, a design feature found in no other similar product. (See illustration)

By engaging the screw lead with rollers which have annular grooves, full line contact is established. This line contact provides dramatic increases in dynamic capacity over ball screws and conventional roller screws.

Spiracon Roller Screws are designed and constructed to facilitate "tailoring" units to your exact requirements.

What Spiracon Roller Screws can do for you.

- Superior Dynamic Capacity
- Greater Predictable Life
- Superior Reliability
- Faster Linear Travel
- Custom Engineered Design
- Operation in Adverse Environments
- Synchronization of Multiple Units
- Repeatable Positioning
- Increased Stiffness
- State-of-the-Art Positioning Accuracy
- Low Noise

For more information, call or write ITW Spiroid

ITW Spiroid offers engineering assistance and fast turn-around of proposals, quotations and prototypes

SPIRACON® *Roller Screws are made in the USA.*
Patented

ITW Spiroid
An Illinois Tool Works Company
2601 North Keeler Avenue
Chicago, Illinois 60639
312/227-2200 TELEX: 820468

Circle 239

efficient motor speed can be maintained while the transmission selects an acceleration rate from driver input.

Binary-logic transmission: This design consists of several stages, each with two speeds or ratios: 1 and "not 1." For a speed increaser, the nonunity ratio is less than 1; for a decreaser, greater than 1. With each stage shifted independently of others, a transmission would have 2^n speeds or increments, where n = number of stages. Therefore, a two-stage transmission can have four speeds. Cascading several stages produces a multiple-speed transmission.

The stage ratio can be found from $\log x = \log R/(2^N - 1)$, where x = basic stage ratio, R = highest or overall ratio, and N = total number of stages. Ratio of the nth stage of an increment is $r_n = x^m$, where $m = 2^n - 1$. Therefore, a six-stage transmission with an initial ratio of 9:1 has $2^6 = 64$ ratios, where x, the basic ratio stage, is 1.0355.

Relative change in vehicle speed is given by $1 - 1/x$, about 3.4% from shift to shift, when the motor is run at constant speed. With all stages shifted to the 1 ratio, the final drive configuration has no meshing gears.

To contrast transmission complexities, a state of the art manual has 12 gear elements, and 4 forward speeds. A binary logic transmission, with the same number of gear elements, would have 6 speeds.

Variable-pitch

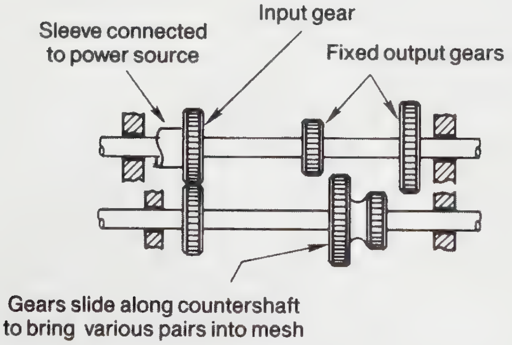
Variable-pitch drives are the simplest of all mechanical adjustable-speed mechanisms. Most of these drives use rubber belts. However, chain and wood-block types are unmatched in regard to their particular strong points.

Belt and chain adjustable-speed drives are "adjustable" in two senses. One type, with stationary control can be adjusted only when not in motion. The pulleys have to be stopped and repositioned manually, usually with at least partial disassembly. The motion-control drives can be adjusted while running, and it is this type that is normally meant when the term "adjustable speed" is used. All subsequent comments here refer to motion-control drives.

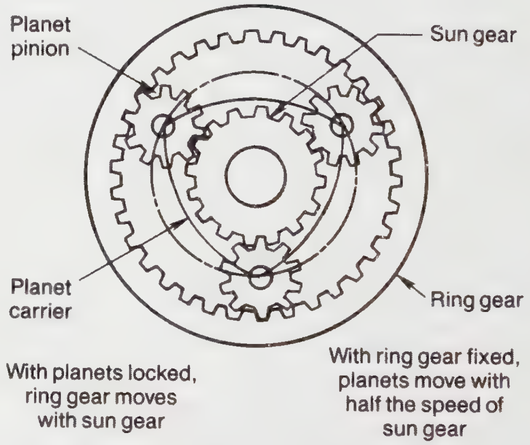
Belt and chain adjustable-speed drives differ from gear drives in that gears provide only a specific number of drive ratios, while belts and chains provide any reduction ratio continuously over a specified range. An adjustable

GEAR TRANSMISSIONS

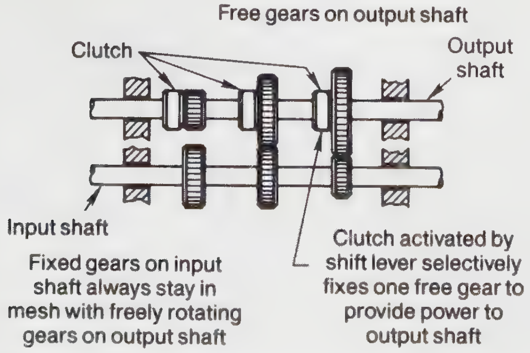
Sliding gear: The simplest of gear transmissions. Gears cannot be shifted while moving; transmission must slow or stop before ratio is changed. Used on machinery and on low-speed vehicles.


Sleeve connected to power source
Input gear
Fixed output gears
Gears slide along countershaft to bring various pairs into mesh

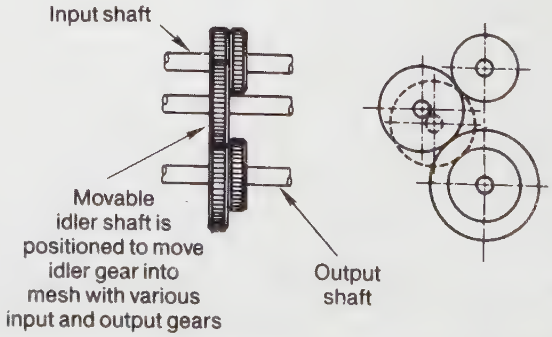
Planetary: Sun, planets, ring gear, and planet carrier can be locked in various combinations to provide a number of drive ratios. The most compact of all gear transmissions, but also the most expensive because of the required clutching and braking elements. Commonly used in automotive transmissions.


Planet pinion
Sun gear
Planet carrier
Ring gear
With planets locked, ring gear moves with sun gear
With ring gear fixed, planets move with half the speed of sun gear

Constant mesh: Gears can be shifted while transmission is running. Used in automotive transmissions and heavy-duty industrial applications.


Free gears on output shaft
Clutch
Output shaft
Input shaft
Fixed gears on input shaft always stay in mesh with freely rotating gears on output shaft
Clutch activated by shift lever selectively fixes one free gear to provide power to output shaft

Idler gear: In a multispeed transmission, it makes small-increment gear changes possible. Often used on machine tools. Transmission must stop before a gear shift.


Input shaft
Movable idler shaft is positioned to move idler gear into mesh with various input and output gears
Output shaft

Browning®

WORLD-CLASS DRIVES from the world-class drive company

Choose the finest drives in the world from the comprehensive line of Browning power transmission equipment…over 30,000 off-the-shelf products that provide an almost unlimited number of item/size/type configurations.

Drive selection is easy. In V-drives alone, Browning offers more than double the range of ratios and centers available from any other source — *all from stock*. Also all-new B5V, the most significant advance in belt drives since the V-groove! In chain drives, gearing, bearing units, couplings, controls, etc., Browning is equally responsive to your requirements. And all are marketed through the worldwide organization of Browning authorized distributors located in every major market area. Call today for the drives you need, when you need them.

Browning

BROWNING MANUFACTURING
EMERSON POWER TRANSMISSION CORP.
MAYSVILLE, KENTUCKY 41056
®606-564-2011 • FAX 606-564-2052

For the Browning Sales Office Nearest You...
Call TOLL-FREE ***1-800-831-5102***

1. **Mounted Bearings** – Ball, Tapered Roller, Spherical Roller
2. **V-Drives** – Classical V-Belt, “358”, B5V, FHP, Synchronous, Variable Speed
3. **Speed Reducers** – Worm Gear, Helical Shaft Mount, Helical In-Line, Parallel Shaft – millions of configurations from stock
4. **Stock Gears** – Spur, Bevel, Miter, Helical, Worms and Worm Gears
5. **Conveyor Pulleys** – Manufactured to ANSI and CEMA standards
6. **Roller Chain Drives** – Chain and Sprockets in a variety of designs
7. **Controls** – A broad choice of AC and DC Drive Controls
8. **Motors** – AC 1/3 to 300 HP; DC 1/4 to 250 HP
9. **Couplings** – Eight different styles ensure the right connection every time

Circle 240

You get
More from
Morse®
and
SEALMASTER®

Call on Morse for everything you need in power transmission equipment.

- Sealmaster® Ball Bearing and Roller Bearing Products
- Clutches and Couplings
- Spherco® Rod Ends and Spherical Bearings
- Chain Drives
- Speed Reducers/Gearmotors
- Sheaves & Timing Belt Drives
- Adjustable Speed Drives and Motors

Morse is dedicated to high quality products and highly trained customer service specialists, ready to assist you at all times. Ask your Morse Distributor for catalogs on any of the above products.

MORSE INDUSTRIAL
EMERSON POWER TRANSMISSION CORP.
620 S. AURORA STREET
ITHACA, NEW YORK 14850 U.S.A.

For the Morse Customer Service Center nearest you ... call TOLL-FREE ***1-800-243-8160***

Sealmaster: Circle 241
Clutches and Couplings: Circle 242
Spherco Rod Ends & Bearings: Circle 243

Chain Drives: Circle 244
Speed Reducers/Gearmotors: Circle 245
Sheaves & Timing Belt Drives: Circle 246
Adjustable Speed Drives & Motors: Circle 247

DI Dynacorp®

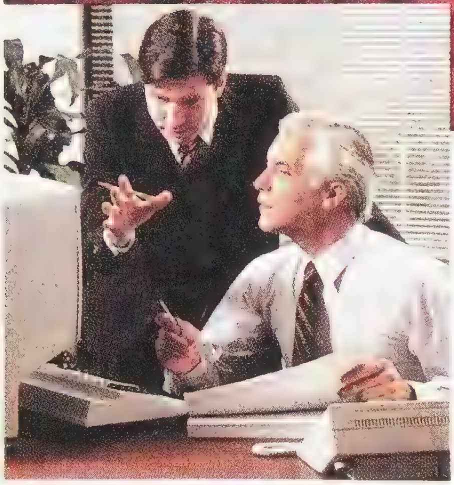
The New Force In Motion Control

NEW!
Catalog DI-91
now available.
Shows complete line
of Clutches and Brakes.
Call, Fax or write
today for your free copy.

DI Dynacorp

Telephone 815-229-3190
Toll-Free 1-800-342-2558
Fax 815-229-4615

DYNACORP
EMERSON POWER TRANSMISSION CORP.
5173-26TH AVENUE
ROCKFORD, ILLINOIS 61109



Not just more choice. More help in choosing.

When you have a problem application and you need a specially engineered solution, there's no substitute for a McGill Sales Engineer for help in choosing the best bearing for the job.

McGill Sales Engineers are a key ingredient in the trust and close working relationship between McGill and our customers. They're bearing specialists adept at helping you create new bearing designs and adapting existing designs to meet your needs.

More choices from McGill

CAMROL®. Cam follower bearings with patented LUBRI-DISC® seal option. In 1/2" through 10" O.D. and metric dimensions to ISO standards.
TRAKROL®. Track roller, guide bearings and wire straighteners in 1-1/2" through 10" O.D.
CAGEROL®. Retainer-type roller bearings designed for high speed applications with minor misalignment and limited lubrication that outstrip the capabilities of ordinary needle bearings.
GUIDEROL®. Center-guided, full complement roller bearings. Provide greater static load ratings and angular rigidity than comparable products.
SPHERE-ROL®. Spherical roller bearings. Bore sizes from 0.9843" to 5.9055".
AIRCRAFT BEARINGS. For housing-supported or cam and track applications. Meet military specs.
SPECIAL BEARINGS. Designed t
your performance criteria.

For name of your nearest McGill Sales Engineer, call 1-800-950-0099. In Canada, 1-800-344-7788.

McGILL MANUFACTURING
EMERSON POWER TRANSMISSION COR
909 N. LAFAYETTE ST.
VALPARAISO, INDIANA 46383

McGILL®
PRECISION BEARINGS

Circle 249

ratio is provided by adjustable-pitch, conical sheaves that can move laterally on shafts. The sheave separation determines the depth at which a belt or chain rides inside the sheave, thereby providing various "effective" sheave diameters. Output may be step-up or step-down. Chain and belt drives also are usually less costly than gear drives. However, they are not as durable as gears and may "wander" a bit from a set ratio while gears provide an exact ratio.

Rubber belt drives typically are rated from 25 to 50 hp at 4,000 to 12,000 rpm. But some units are rated as low as 2.5 hp for small motor scooters, and some giant versions are rated at over 80 hp for large combines and racing snowmobiles. The largest industrial drives, however, are normally rated at about 100 hp. The typical price for a medium range belt is from $40 to $80, making the rubber belt one of the least-expensive types of adjustable-speed drives.

Belt drives are usually adjusted manually with vernier mechanisms for precise control. Drives may be operated remotely with a small electric motor attached to the drive-control screw. In addition, belt drives may be designed to vary ratios automatically in response to torque or speed changes.

Efficiency of belt drives is high — usually about 95%. And belts provide good overload and jam protection because the belt slips when overloaded. However, prolonged slip can cause excessive heat and belt wear.

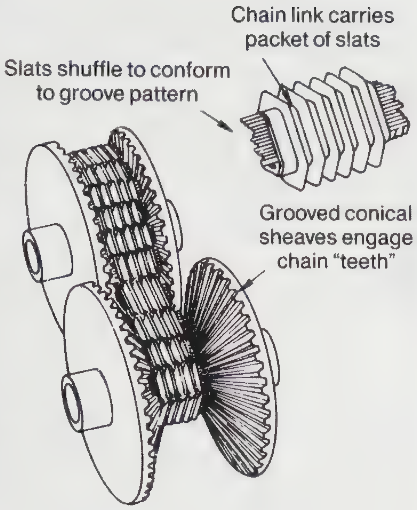
Even when belt-drive operation is within rated speed and horsepower conditions, heat buildup is still a major factor contributing to belt deterioration. Thus, most belt drives must be well ventilated to dissipate belt heat. This heat and belt wear tend to produce 5 to 10% variation in drive ratio, so speed-control accuracy is relatively low for most models.

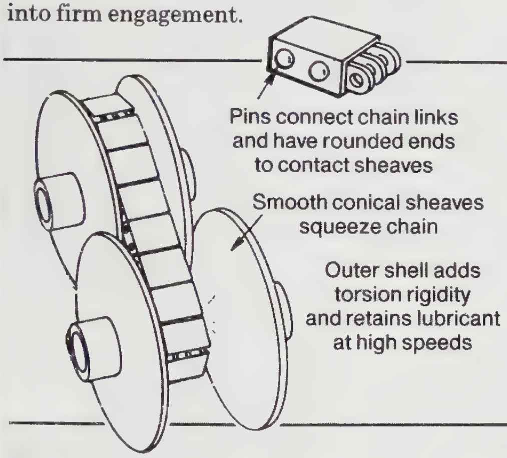
There are three standard types of belts for adjustable-speed drives. Classical V-belts are used for limited speed variations to about 1:2. Industrial variable-speed V-belts with wide, thin cross sections are used for applications requiring significant speed variation to 8:1 and transmit up to 32 hp. Agricultural belts are generally thicker than industrial types and can transmit higher horsepower with maximum speed variation to about 4:1. In addition to these, there are also belts custom designed for high-stress applications such as automobiles, recreational vehicles, and heavy machinery.

Industrial variable-speed: These drives are attractive because of their simplicity, efficiency, and wide power

VARIABLE-PITCH DRIVES

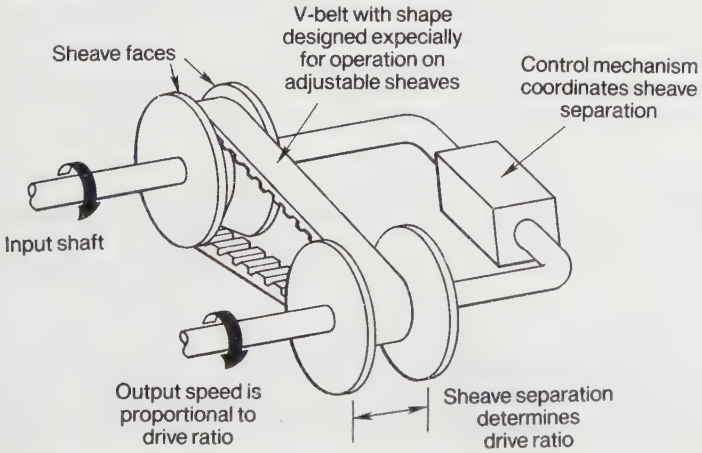
Laminated metal chain: A durable drive limited to 25 hp. Input speed is limited to 500 rpm for a ratio of 4:1, and 450 rpm for ratios up to 6:1. In low-power models, allowable speeds are high and maximum ratio is 6:1. Provides positive, no-slip grip capable of high ratio accuracy. More expensive than V-belt drives but capable of operating at higher temperatures. The power chain (sometimes referred to as a "metal belt") is specially designed with an appearance similar to a timing chain, but with sheave engagement made by a stack of thin steel slats inserted crosswise through the links. The slats slide or deflect so that the stack conforms to radial grooves in the sheave, allowing the chain to "nest" into firm engagement.


Chain link carries packet of slats
Slats shuffle to conform to groove pattern
Grooved conical sheaves engage chain "teeth"


Pins connect chain links and have rounded ends to contact sheaves
Smooth conical sheaves squeeze chain
Outer shell adds torsion rigidity and retains lubricant at high speeds

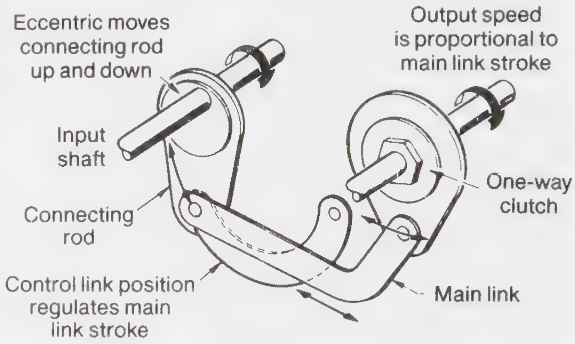
Extended-pin chain: Capable of higher speeds, power, and ratio variations than the drive based on laminated metal chain. The chain has side-facing pins that engage the sheave.

Rubber belt: The least expensive and smoothest running of all adjustable-speed mechanical drives. This type is a high-speed/low-torque system which is generally smaller than other mechanical drives. Most drives use a specially designed wide section belt to ensure correct sheave contact and flexing characteristics. The drives that are the most popular and widely used are "power package" designs which combine a motor, adjustable-pitch sheaves, and a gear reducer as an integral unit. Single belt units can transmit up to 50 hp, with capacities up to 100 hp being offered in a double belt design. Speed ranges from 2:1 up to 10:1 are available. Belt replacement is extremely easy and can be performed in field. Belt does not require lubrication.


Sheave faces
V-belt with shape designed expecially for operation on adjustable sheaves
Control mechanism coordinates sheave separation
Input shaft
Output speed is proportional to drive ratio
Sheave separation determines drive ratio

VARIABLE-STROKE DRIVE

Variable-stroke drive regulates output speed with one-way clutches that rotate an output shaft in response to reciprocating motion. In the input section of the drive, a rotating input shaft turns an eccentric member, which moves a connecting rod up and down which, in turn, moves a linkage back and forth. This linkage rotates one-way clutches connected to the output shaft. Output speed is regulated with a control lever that changes the angle of the connecting rod, which changes link stroke.


Eccentric moves connecting rod up and down
Output speed is proportional to main link stroke
Input shaft
One-way clutch
Connecting rod
Control link position regulates main link stroke
Main link

range. Until recently, the classical variable-speed belt drive used splined hubs to transmit power and change position. But the hubs require greasing about every 100 h; otherwise, they can freeze into position and become single speed devices. Extended use also can freeze pulleys through fretting corrosion.

One solution to this problem is a coating of solid lubricant, which allows the sheaves to move even after long periods at one speed. Also, interchangeable collets enable one variable sheave to work on a variety of shaft sizes, rather than marrying it to one. Recent designs have passed the 50-hp limit and now transmit up to 100 hp. Ratios are also creeping up; previously, 8:1 was tops, now it is 11:1.

One variation on the movable pulley wall is the movable friction surface. Here, the friction surface is divided into segments that move radially to change pulley diameter. A cone-shaped device is driven axially to move the friction surfaces while keeping them centered in the same plane. Very fine adjustment is made easily. For instance, a 1-rpm change, less than 0.1%, is possible at full speed. Also, V-ribbed belts contact a greater surface area. Hence, smaller units generally transmit more power. Maximum ratios are somewhat limited, usually less than 2:1.

Traction

Traction drives have been around for a long time but have not made a major impact on the power-transmission industry. The main obstacle to their increased use has been a lack of confidence in the fact that two smooth rollers can transmit force through a fluid. However, the block to using traction drives appears to be dissipating, aided by design changes that have improved capabilities. These advances, combined with ease of maintenance are making traction drives formidable competitors to conventional adjustable-speed drives.

Presently, the ball variator accounts for the majority of traction drives sold; however, Beier disc and ring cone drives also are widely used. In addition, planetary, toroidal, and ring roller devices have carved out niches as commercially proven traction drives. The friction drive (which some experts would not classify as a traction drive) rounds out the field of traction drives.

In general, traction drives are finding applications where compactness, ruggedness, and speed-control accuracy are primary concerns. The micrometer speed-setting dial on most traction drives attests to their inherent accuracy in maintaining a specific output speed. In addition, most conventional adjustable-speed drives require additional components to start smoothly. Traction drives, in contrast, automatically provide the extra torque needed at reduced speeds.

Variable-stroke

Variable-stroke drives are most widely used in low-speed applications

How traction drives stack up

Type	Power (hp)	Speed ratio	Output speed at min hp (rpm)	Output speed at max hp (rpm)	Driver input speed (rpm)	Speed holding capability (%)	Efficiency (%)
Ball variator							
Cleveland Gear	16	9:1	1,000-5,400	1,000-5.400	750-1,800	0.1-4	90
Heynau-Minidrive	0.24	9:1	583-5,250	583-5,250	1,750	0.1	85
Kopp Type-M	2.2	12:1	250-3,600	250-3,600	1,500/1,800	0.1-4	75-90
Unidynamics-Winkopp	16.8	9:1	600-5,400	600-5,400	600-1,800	0.1-4	90
Beier disc	7.5	12:1	108-1,296	108-1,296	675-1,750	0.1	75-87
Sumitomo	200	4:1	350-1,400	350-1,400	675-1,750	0.1	75-87
Fixed ratio							
Nasvytis	500	250:1	0-480,000	0-480,000	0-480,000	0.1-1.3	90-96
Friction disc							
Andantex Univar	10.1	5:1	450-2,250	490-1,190	600-3,600	—	—
Eurodrive Vairmot	15	5:1	450-2,250	490-1,190	600-3,600	—	—
PT Components							
Link Belt-TD	15	5:1	450-2,250	490-1,190	600-3,600	—	—
Sumitomo SM-Beister	7.5	5:1	450-2,250	1,800-2,250	600-3,600	—	—
Planetary							
Lenze-Disco	25	6:1	189-1,130	240-1,200	1,725	0.5	75-84
Ring cone							
Kopp Type-K	100	12:1	185-2,220	300-1,800	1,500/1,800	0.03	93
Graham R-X	20	∞	0-600	0-600	1,750 or less	0.9	82
Ring roller							
Heynau H-Drive	5.3	9:1	583-5,250	583-5,250	1,750	0.1	85
Graham	5	∞	0-1,100	0-400	3,450 or less	0.1	85-90
Parker-FU	82	6:1	340-2,040	720-1,440	1,750	0.3	87-93
Toriodal							
David Brown Sadivar	5.3	7:1	540-3,780	540-3,780	1,440	3	80

SUMITOMO
SM-CYCLO GEARMOTORS

SHOCK ABSORBER

THE AVAILABLE SOLUTION

SM-CYCLO Gearmotors and Brake Gearmotors will absorb 500% shock overloads. They're reliable and durable. We back them with a 2-year warranty to prove it.

SUMITOMO, a world leader in power transmission, has produced well over 4 million SM-CYCLO® Speed Reducers and SM-CYCLO® Gearmotors.

Because of their unique advantages, exceptional performance and reliability, SM-CYCLO® Gearmotors are in use in a wide variety of industries worldwide. SM-CYCLO® Gearmotors have gained special recognition where severe working conditions prevail and where equipment breakdowns cannot be tolerated.

CAPACITIES: Horsepowers to 150,
Torques to 521,000 in lbs., Ratios to 7,500:1.

We offer very competitive pricing and a national sales, engineering and service organization. Our network of representatives and distributors also offer you comprehensive, fast and efficient service.

CONTACT US TODAY FOR FREE PRICE AND SELECTION GUIDE

SUMITOMO MACHINERY CORP. OF AMERICA
Power Transmission Products
4200 Holland Blvd., Chesapeake, VA 23323
(804) 485-3355 • FAX: (804) 487-3193

STOCKING AND ASSEMBLY
- Los Angeles, CA
- Chicago, IL
- Dallas, TX
- Toronto, Canada
- Vancouver, Canada
- Monterrey, Mexico

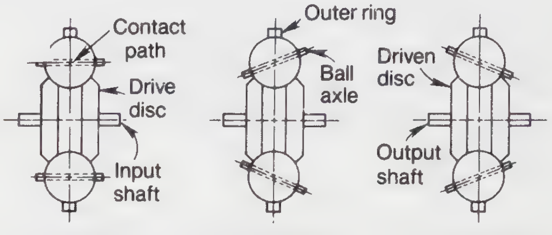
Circle 250

TRACTION DRIVES

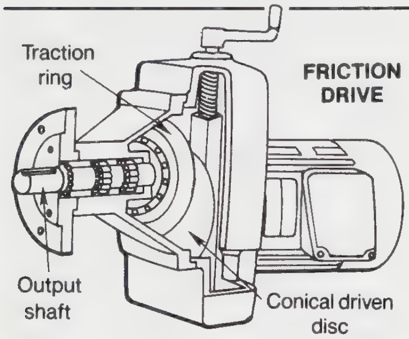
The operation of most traction drives is based on the rolling contact between two smooth and unequally sized rollers. Traction forces are transferred between the rollers through a traction fluid. This fluid is pressurized by normal force, N applied to both rollers. The traction force, T, is proportional to N and the traction coefficient, μ, of the fluid. The normal force must be large enough to prevent destructive slipping of the rollers.

The traction fluid allows for elastohydrodynamic (EHD) lubrication. That is, the traction fluid separates the rollers (slightly deformed at the contact surfaces) by a highly compressed, extremely thin lubricant film. Contact stresses of about 150,000 psi or more are experienced by the lubricant, which changes from a liquid to a plastic solid and then back to a liquid. Although the use of synthetic cycolaliphatic traction fluid is usually recommended, naphthenic mineral oils were used in the original traction drives.

Ball variator: Motion is transmitted through idler-type ball. Tilt of ball determines ratio. In sketch, input wheel engages a large radius of the ball while output is driven through a smaller radius, producing a reduction ratio.



1:1 RATIO 1:3 DECREASE 3:1 INCREASE



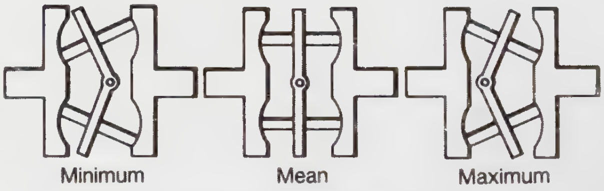
FRICTION DRIVE

Friction drive: Torque is transmitted through point contact between a friction ring (usually phenolic) and a motor-driven steel conical disc. Speed is adjusted by varying relative running diameters. That is, the farther the friction ring rides from the center of the conical disc, the greater the output speed.

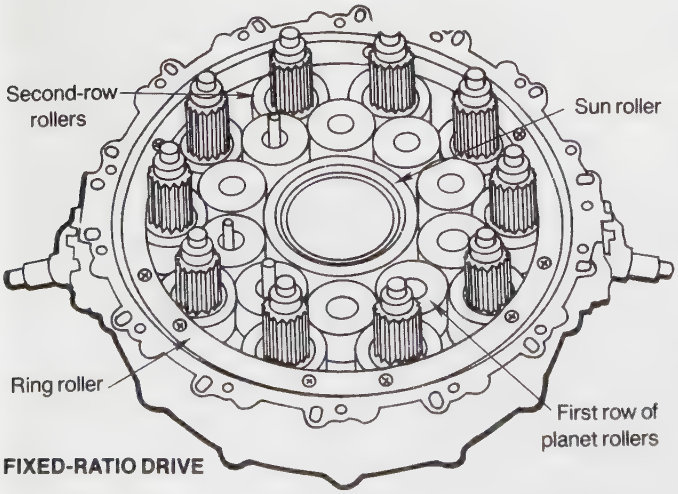
Low first cost and freedom from lubricant contamination (interior or exterior) makes this a widely used friction drive. However, limited shock and overload capacity, and a low speed-holding ability narrows possible application areas.

Typical applications include: conveyor lines, food plants, and glass plants. The units withstand daily washdowns and do not require frequent repairs. They compete favorably with belt-type mechanical and electrical adjustable-speed drives.

Toroidal drive: Has had a great deal of attention over the years and has been the subject of more patents than any other type. Practical models are limited to light-duty instrument drives, but automotive and industrial variations are now under development. This drive has the potential for serving as automatic transmissions in light automobiles.



THREE-ROLLER TOROIDAL

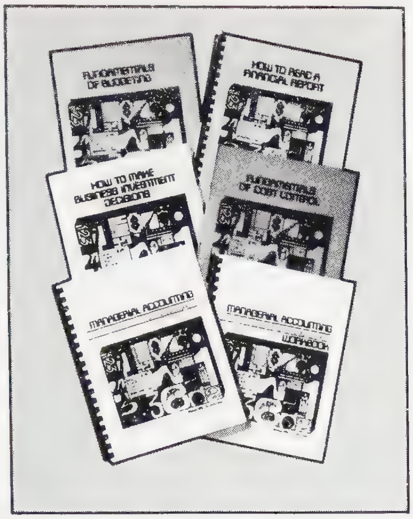


FIXED-RATIO DRIVE

Fixed-ratio drive: This planetary drive consists of planetary clusters of two or more rows of rollers maintaining contact at fixed radii. In the case of a speed reducer, the center or sun roller serves as the input roller while the ring roller, which encloses all the rollers within it, is the output roller. All of the planet rollers are nonorbiting with the outermost row of planets being supported by bearings. The roles of the sun and ring rollers may be reversed creating a speed increaser rather than a speed reducer. If a spider is connected to the planet rollers, it becomes either the input or output if the sun or ring are fixed.

Prototypes provided speed reduction for: a 150-hp automotive gas turbine, 14:1 ratio of 45,000 rpm; a 500-hp hybrid (traction/gear) helicopter transmission; and a 210:1 ratio, propeller pitch-control mechanism. Industrial units included a 25-hp bearing test rig, 14:1 ratio at 36,000 and 65,000 rpm; and a 3:1 ratio, single-row roller drive for a 55 hp, 39,000-rpm aircraft generator.

continued on page 206



WHAT EVERY MANAGER NEEDS TO KNOW ABOUT ACCOUNTING

in this Easy-To-Use Self-Study Course Series

A 50-hour course of instruction at less than $2.00 per hour. Study them one-at-a-time . . . or buy all five courses at a special savings. Either way, 15-day review option applies.

Item X38	***Managerial Accounting for Non-Financial Managers*** *course and work book*	*$32.50*
Item X30	***Fundamentals of Cost Control***	*$20.00*
Item X29	***How to Read a Financial Report*** *(ratio analysis)*	*$24.00*
Item X36	***How to Make Business Investment Decisions*** *(the time value of money)*	*$20.00*
Item X15	***Fundamentals of Budgeting***	*$20.00*
Item S08	***The Complete Five-course Financial Planning Series at a special price of $99.50 (save $17).***	

Begin your personal financial development program today.

Complete the coupon below and mail to:

Penton Education Division • 1100 Superior Avenue • Cleveland, Ohio 44114 • 216/696-7000

Please send the items checked below. I understand that I may review them for 15 days and, if not satisfied, return them for full refund or credit.

Quantity	Item No.	Quantity	Item No.
______	X15	______	X36
______	X29	______	X38
______	X30	______	S08

☐ My payment is enclosed for postage-free shipment in the U.S. and Canada.

☐ Bill my company. My purchase order is enclosed.

Charge my ☐ Visa ☐ MasterCard ☐ American Express.

Acct. No. ______________________ Exp. date __________

Name ______________________

Title ______________________

Company ______________________

Address **(no P.O. Box)** ______________________

City ______________ State ______ Zip ______

Signature ______________________

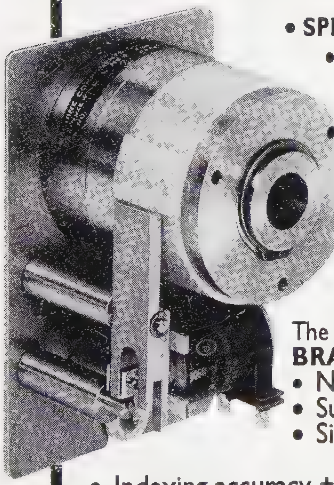
☐ Please send your brochure of other management, professional and technical courses.

Penton Education Division • 1100 Superior Avenue
Cleveland, Ohio 44114

Circle 251

CLUTCH BRAKES

CNR SERIES PLUS



- SPRING WRAPPED DESIGN
- SOLENOID OPERATED
- NON REVERSING
- FREE FROM RADIAL LOADS
- TORQUES: 50 TO 500 LB.-IN.
- ACCURATE STARTING & STOPPING OF LOADS

The **CNR** series **CLUTCH BRAKES** feature:

- No radial loads on clutch input
- Superior Spring technology
- Single or multiple indexing steps per revolution.
- Indexing accuracy ± 1°
- Errors non-cumulative
- Output cannot be back driven
- Unidirectional rotation
- Clamp coupling to output shaft. Keyways not necessary
- External phasing capability.
- Load lock when solenoid is off
- Solenoid voltages 12, 24 VDC; 110 VAC, 60HZ.

Send for catalog 18D

OUR ENGINEERS WILL MODIFY DESIGNS TO MEET YOUR SPECIFIC REQUIREMENTS

MACHINE COMPONENTS CORPORATION
70 NEWTOWN ROAD
PLAINVIEW, NY 11803 • 516 694-7222 FAX: 516 694-7252

Circle 252

GROUND GEAR SPECIALISTS

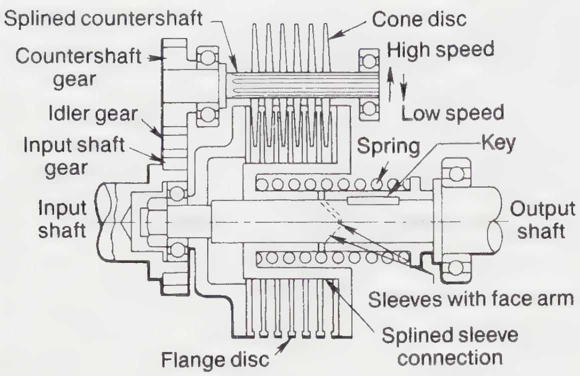
If you're a Design Engineer, you know the meaning of precision. Miss by a mil and you miss by a mile. Niagara Gear is a contract manufacturer of precision spur, helical and pump gears to AGMA Class 15 with crowning. We are especially proud of our reputation as a Reishauer ground gear specialist. Niagara Gear has quality inspection systems in place to meet MIL-I-45208 and Calibration Standard MIL-STD-45662A. Nital Etch Inspection and Charting are available. Niagara Gear delivers. On price. On quality. And on time. We are as close as a phone call away.

NIAGARA
GEAR CORPORATION

941 Military Road
Buffalo, N.Y. 14217
Phone: (716) 874-3131
Fax: (716) 874-9003

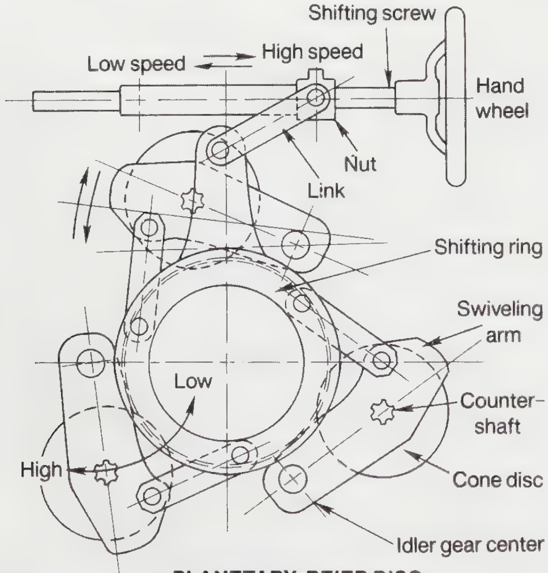
Circle 253

continued from page 204



Planetary: The input shaft drives the outer sun through a key. The inner sun adjoins the outer sun. Between the two suns, from three to eight conical planets are engaged in either a small or large running diameter. The suns are held in place by a cup spring cluster.

The planets are supported outside the suns by two outer rings. The stationary outer ring is held in place by the drive housing. The moveable outer ring is adjustable in radial and axial positions. Speed is adjusted by varying the gap between outer rings.



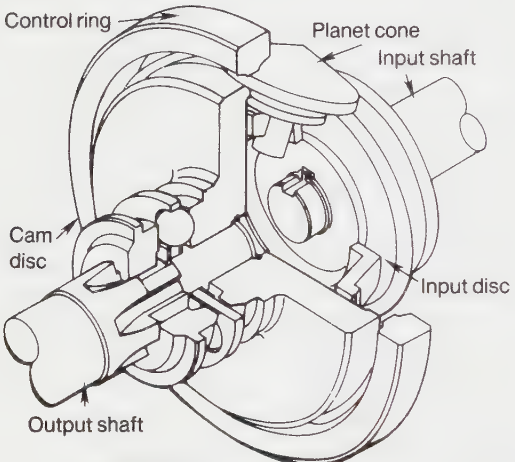
PLANETARY, BEIER DISC

The rotating planets, which are driven by the inner suns, drive the planet carrier, which houses the planet bearings holding the planet axles. The planet carrier, turns the output shaft through a key.

Speed is adjusted while the drive is running. However, adjustment to the minimum output speed can be done while the drive is stationary. Applications include spindle drives and mixing and metering drives.

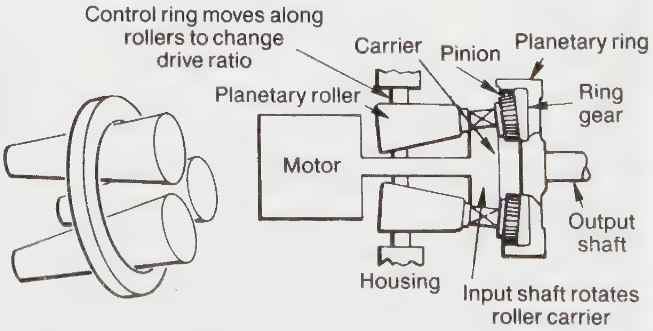
Beier disc: Torque is transmitted primarily by viscous drag in the lubricant, and slip normally ranges from 2 to 4%. The drive produces constant torque rather than constant power. Contact areas are large and contact pressures are low compared to the true traction drives.

Ring/cone: Transmits power from the input shaft through a pressure plate and drive disc to conical rollers, through the drive ring, pressure balls, and drive flange to the output shaft. Movement of the roller carrier increases or decreases the drive roller diameter in contact with the drive disc and drive ring.



RING/CONE

Ring roller: A nonrotating metal ring makes contact with tapered rollers. Drive ends of rollers are planet members engaging a planetary ring connected to the output shaft. Zero speed may be at one end of the speed range or at mid-range, providing a reversible drive.


Control ring moves along rollers to change drive ratio
Carrier
Pinion
Planetary ring
Planetary roller
Ring gear
Motor
Output shaft
Housing
Input shaft rotates roller carrier

below 1.5 hp. They compete mainly with belt and chain drives and have running efficiencies near 80%. However, unlike belts, variable-stroke drives operate effectively at near-zero output speed.

Speed output is continuously variable from zero to one-fourth input speed. Speeds are maintained and repeated within 1% of maximum in the upper 90% of the range, providing output load and input speed are constant.

Because they are positively coupled devices, basic variable-stroke drives do not slip and, therefore, do not provide overload protection. Thus, variable-stroke drives are usually conservatively rated to provide a large safety factor. Some models have built-in mechanisms that slip at overload before the drive is destroyed. These mechanisms are designed not for continuous duty but for occasional protection against overload. In most models, the disconnect point is substantially higher than the drive rating, and the reconnect point is at or near the torque rating.

Most variable-stroke drives have a control handle that can be actuated manually or hooked mechanically, pneumatically, or electrically to the controlled machine.

Cable drives

In recent years, power transmissions in the 0 to 3-hp range have tended to be dc drives. However, one gearless transmission bucks this trend. It consists of aircraft-quality cable wrapped in opposite directions around driver and driven shafts. Cables are anchored to the largest shaft and preloaded to eliminate backlash, an advantage over geared transmissions. Cable drives work equally well as speed increasers or decreasers. Although rotation is limited by the length of cable the shafts can handle, the drives are well suited where continuous rotation is not required.

Torsional stiffness is 10^5 lb-in./rad and higher for single cable drives. Stiffness varies with the square of the larger shaft radius; thus, doubling shaft size improves stiffness by a factor of four. Single-wrap cable drives can transmit up to 72 lb-in. and provide a useful life exceeding many millions of cycles. Torque capacity for multiple cable drives can range to 76,000 lb-ft, but speed is usually less than 1 rpm. The devices have found homes on turntables for silicon wafer saws and in positioning units for directional solar panels. ■

THE TEFLON® SEAL WITH A MEMORY!

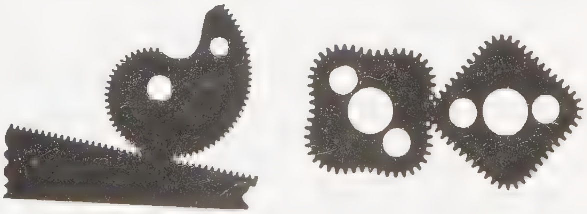
Teflon is the world's most versatile seal material but it doesn't have a memory! Furon has a variety of spring designs which provide permanent resiliency to this superlative plastic. Capabilities from −320°F to 600°F, near universal chemical compatibility, and ultra low friction. Write for your free Design Catalog... before you forget!

Resilient U-Shaped Spring

furon
MECHANICAL SEAL DIVISION
4412 Corporate Center Drive
Los Alamitos, CA 90720
(714) 995-1818 FAX (714) 761-1270
1-800-544-0080

Circle 254

FOR NONLINEAR MOTION–
NONCIRCULAR GEARS



Noncircular gears are suited for packaging machines, rotary shears, pumps, altimeters and other instruments and mechanisms which require nonlinear motion. Standard elliptical gears are in stock, or we will design and manufacture to your specifications.
Call or write for free brochure.

CUNNINGHAM
INDUSTRIES, INC.

102 Lincoln Ave. Stamford CT 06902
800-466-2942 203-324-2942

Circle 255

Gaskets, seals, packings

Preventing leaks and contaminant ingression keeps a system operating as intended.

Seal selection is often an imprecise and time-consuming process, involving numerous compromises. Some qualities a seal must have are obvious. These include good sealability, to contain the fluids for which it is designed. Also, the seal must be compatible with the fluids it contacts to maintain its physical integrity. Dynamic seals must have good wear resistance to ensure long life.

Other, not so obvious factors, include having sufficient strength to resist extrusion under maximum temperature and pressure. Stability is required to resist twisting and deformation in the seal cavity. Finally, overall economics must be considered.

Unfortunately, some compromise among the desired features is almost always necessary because these features conflict with one another. Loading of a dynamic seal is a good example. High loading between seal and moving surface results in good sealability but also produces high friction and wear. Reducing this load increases seal life but permits more fluid to escape at low pressure.

Seal selection is by no means an exact science. In any application, the designer must decide which factor has precedence. Also, the seal often is so critical to the system in which the seal is used that it should be considered early in the design of that system. In struggling with these design factors, many OEM seal users are using the seal manufacturers' design expertise.

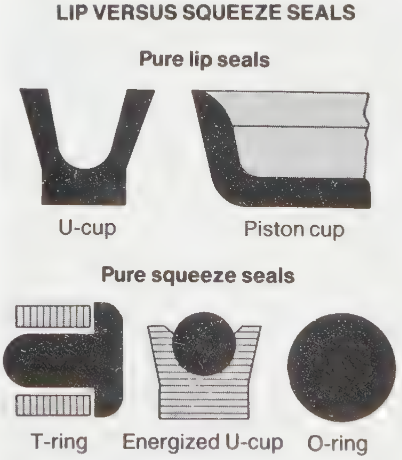
Compression seals

Compression seals come in a variety of shapes, and are characterized by the high unit load exhibited between seal and walls. These are generally the seals of choice in static sealing applications, which are presumed to be totally leak free. This is especially important at low pressures, when the seal alone and not system pressure must supply the sealing force. They can also be used in light-duty dynamic applications because of their adequate performance at low cost.

Probably the most widely used compression seal is the simple O-ring. An O-ring can be considered an incompressible viscous fluid with very high surface tension. This "fluid" is forced by mechanical or hydraulic pressure to flow into the sealing cavity, blocking the flow of the less-viscous fluid being sealed. Properly installed, the O-ring is squeezed about 10 to 15% of its original cross-sectional diameter. The compression absorbs the tolerance stack up between mating surfaces (or between shaft and gland in dynamic applications), and forces the elastomer into microscopic surface grooves on mating parts.

Under moderate pressure, the O-ring flows up to, but not into, the clearance gap between components. As pressure rises, both sealing force and contact area increase. At its pressure limit, which depends on seal dimensions and hardness, part of the O-ring starts to extrude into the clearance gap. At this point, the seal can shear, leading to failure.

Backup rings protect O-rings and other squeeze packings from extrusion by high pressures. They are generally used at pressures exceeding 1,500 psi, and can be used at lower pressures when diametral clearances are large.



LIP VERSUS SQUEEZE SEALS

Pure lip seals have the lowest friction and wear of any seal type, but tend to allow seepage at low pressure. Pure squeeze seals, on the other hand, have excellent low pressure sealing ability, at the cost of high friction and wear.

Like backup rings, caps or slippers prevent extrusion at high pressure. However, caps also protect against friction in reciprocating applications. They are made of PTFE and come in a variety of shapes.

Compression set of the elastomer is of prime importance when choosing a static seal. Excessive compression set found in lower grade rubber reduces the effective sealing force, resulting in leakage. High temperatures accelerate this condition.

To counteract compression set, a controlled amount of volume swell of the rubber, caused by absorption of hydraulic fluid, is preferred. In most applications, 5 to 15% swell is recommended for a static seal. In light-duty dynamic applications, volume swell can soften the elastomer and increase friction, leading to heat buildup. Thus, swell in dynamic applications should be limited to 5 to 6%.

O-rings are also suitable for light-duty rotary applications. Generally, they provide satisfactory life if running speeds are limited to 750 fpm, and sealed pressures to 200 psi. However, some seal manufacturers permit O-ring use at speeds to 1,500 fpm and pressures to 800 psi.

The key to using O-rings in rotary applications is avoiding the Gow-Joule effect — the tendency of elastomers under tension to shrink when heated. This sets up a destructive cycle in which friction and heat give rise to even more friction and heat until the seal fails. This is avoided by using the O-ring in compression, rather than tension.

Compression seals are available in a wide variety of shapes. Rectangular rings, quad rings, and H-rings are examples of seals that do much the same job as O-rings, but fill the gland better and have a more stable geometry.

Teflon cap seals consist of a compression seal with a Teflon cap. They are primarily used in applications where high velocity may cause frictional heat buildup. PTFE is used because of a low coefficient of friction and

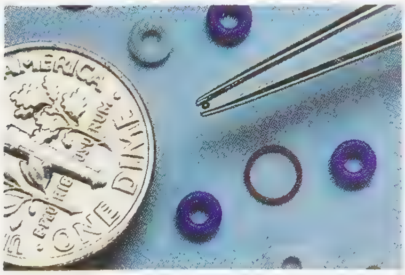
A New Dimension in Sealing Solutions

APPLE RUBBER PRODUCTS INC.

PRODUCTS

Enter a World of Sealing Products and Services.

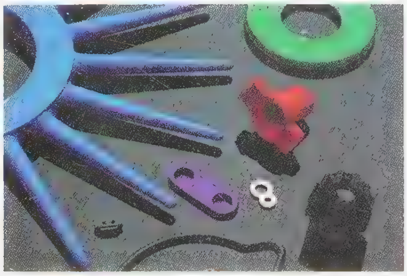
O-Rings in Stock Including AS-568A Standard and Metric Sizes - Apple Rubber stocks the largest inventory of seals in the industry. Standards. Metrics. Unusual sizes. This means most of your O-ring requirements can be shipped immediately, saving you time and money.



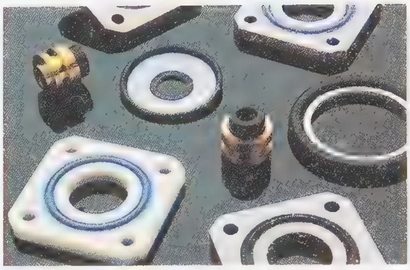
MicrOring™ Seals - These innovative, tiny O-rings were introduced by Apple Rubber to solve the problem of sealing in today's microminiature applications. We offer over 1,000 sizes of MicrOring™ Seals, from as small as .008" up to .039" I.D.

MacrOring™ Seals - For larger applications, we offer MacrOring™ oversized O-rings available from 5" I.D. up to 800" I.D. and larger. MacrOrings are manufactured to hold I.D. tolerances equal to or superior to traditional, molded large O-rings.

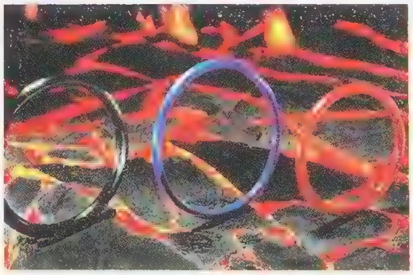
Whatever the application, Apple Rubber is the one company that's doing more in sealing technology than anyone else. From design through manufacturing to certification, the scope of Apple Rubber's capabilities assures complete sealing solutions.



Custom Molded Shapes - We can assist you in custom designing unusual, all-rubber shaped seals specifically for your application, including microminiature shapes for your smaller designs. Apple will be with you at every step - from design to prototype and through production.



Composite Seals - Complicated parts such as rubber-bonded-to-plastic and rubber-bonded-to-metal may be your sealing solution. Often these seals are easier to install and allow for automatic assembly to reduce installation time and costs.



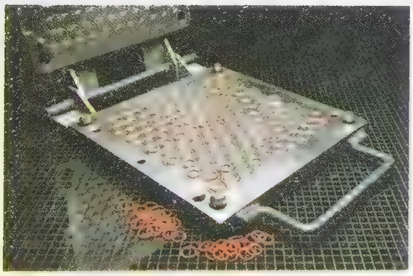
The Right Materials and Hardnesses - Apple Rubber has the materials for most applications, from standard to hard-to-find, including Viton,® Fluorosilicone, Polyurethane and Teflon.® If you're having difficulty finding softer durometer, high temperature or other unique compounds, you'll find them at Apple Rubber.

SERVICES

Call Apple Rubber at 1-800-828-7745

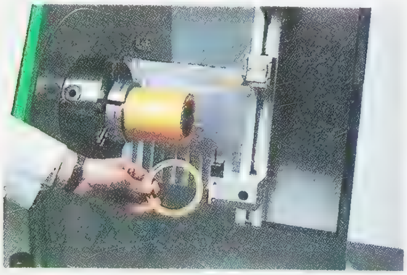
FAX: (716) 684-8302

Design Engineering - When you call Apple Rubber, one of our project engineers will stay with you from design to prototype to production. Apple's wide experience and love of a challenge are your best sealing resources.

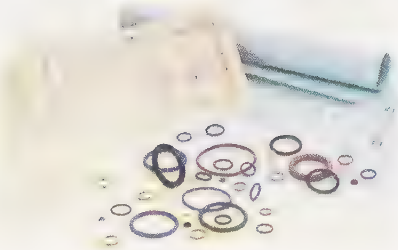


Complete Manufacturing - Apple's complete manufacturing capabilities mean fast response to your sealing needs, for large or small runs. Molding. Machining. Bonding. Whatever the requirement, Apple has the tools to get the job done.

Prototyping- In all product development, time is **the** critical factor. By utilizing advanced processes, such as our ExpresSeal℠ System, Apple Rubber's Prototype Group drastically reduces the design and development cycle. This gives you the competitive edge.



For more information contact
Apple Rubber Products,
310 Erie Street,
Lancaster, New York,
U.S.A. 14086-9908.
1-800-828-7745
FAX: (716) 684-8302
Tel: (716) 684-6560
Telex: 91-251
Or complete the card and mail it to us.

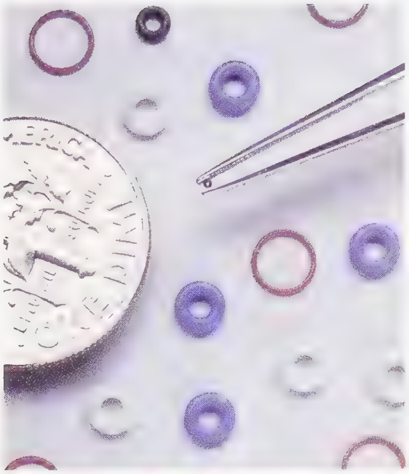


Comprehensive Testing - We offer comprehensive, careful testing of your seals through AppleLab,™ one of the most stringent quality assurance programs in the industry. We are the only seal company to offer quality assurance that routinely includes **both** dimensional and material validation. And because we offer full documentation, our program allows you to eliminate costly incoming inspection.

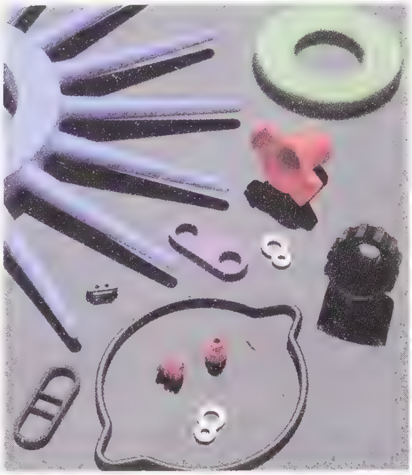
Dealing Direct - With Apple Rubber, you deal direct, eliminating the middleman. This means time saved, better communications and direct access to Apple's experience and expertise. By dealing direct, you can be assured of **Apple's** quality and accountability.

Research and Development - If you require a truly unique solution, Apple Rubber has the resources to explore and develop new designs, materials and processes. In fact, we do it every day!

Which sealing problem is most like yours?



The tiniest seal for a microminiature application. Apple Rubber MicrOrings,™ are available in over 1,000 sizes, including .008" I.D., the world's smallest O-ring.



A custom seal with a most unusual shape. Apple Rubber can provide any custom molded shape specifically for your application, from the most exotic seal to microminiature shapes.

A composite seal designed for your specifications. Apple Rubber custom-designs composite seals, including the most complex parts such as rubber-bonded-to-metal.

Prototypes needed yesterday. Apple Rubber custom-engineers prototype seals and shapes, drastically reducing development time which allows for delivery in days.

Hard-to-find oversized O-rings. Apple Rubber MacrOrings™ are manufactured up to 800" I.D. and larger, to hold I.D. tolerances equal to or superior to traditional, large O-rings.

Standard or metric O-ring sizes delivered right away. Apple Rubber stocks the largest inventory of O-rings in the industry, delivered fast, direct from the source.

Apple Rubber solved them all.

Apple Rubber can solve your sealing problems, from the most complex to the more conventional. From design and prototyping, through manufacturing to certification, we've got the expertise, products and services to deliver virtually any seal for any application. For more information, including a free copy of our capabilities brochure, call us at 1-800-828-7745 FAX (716) 684-8302, or write Apple Rubber Products, 310 Erie Street, Lancaster N Y 14086.

APPLE RUBBER PRODUCTS INC.™

The Sealing Solutions Company

1-800-828-7745

Circle 256

excellent wear characteristics. But PTFE does not seal as well as rubber and is susceptible to damage from solid contaminants.

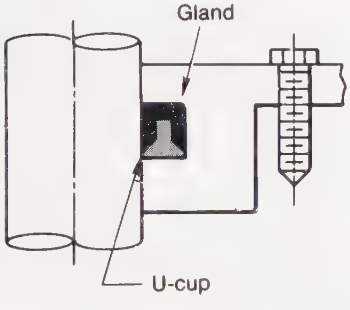
O-ring loaded lip seals are a good choice when wear resistance and low-pressure sealing are necessary. Urethane, for example, exhibits excellent abrasion and tear resistance, but has poor compression set characteristics. Adding an O-ring to a urethane lip seal provides the compressive sealing force needed at low pressure.

Pressure-energized seals

Dynamic sealing applications often call for pressure-energized seals. In the absence of system pressure, seals such as pure lip seals have only the light load of deflected lips to provide a sealing line. They have a definite tendency to seep at low pressures. As system pressure increases, the flexible lips are compressed against shaft and walls, increasing sealing effectiveness. The advantage is that the relatively small area in contact with the dynamic surface produces little friction, giving long life and good sealing at high speeds.

U-cups are suitable for applications to 5,000 psi. As pressure increases, harder elastomers and backup rings should be used. These seals are available in a number of shapes.

Asymmetrical U-cups are pressure-activated lip seals with different lip profiles for sealing dynamic and static surfaces. They are usually not adequate for low-pressure sealing. Symmetrical U-cups, while not as effective, are widely used because of their lower cost, and can be used as either a piston or rod seal.



U-CUP

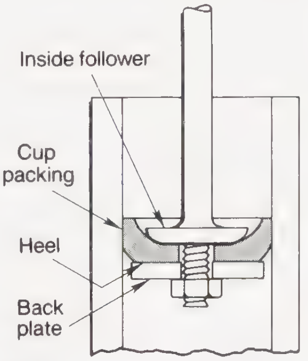
For rubber U-cups, the metal support ring sometimes used in gland installations should not exert undue pressure on the packing, since it retracts the lips and spreads the heel. The base of the supporting ring should be designed to properly center the ring. Internal threads should be offset to protect seal lips.

V-rings are installed in sets, each set consisting of a number of rings, a male adapter, and a female adapter. The number of rings in a set depends on pressure and the ring material.

The function of the male and female adapters is to support the rings. The female adapter is the more critical, and should have the same included angle as the rings (usually 90°). The male adapter should have the same angle as the female.

A small amount of leakage must be allowed, to provide a lubrication film between the metal and rubber of the furthest sealing lips. Otherwise, the seal will "run dry" and be destroyed by heat buildup. For zero low-pressure leakage, a urethane vee should be inserted as the last (outer) member of the vee stack.

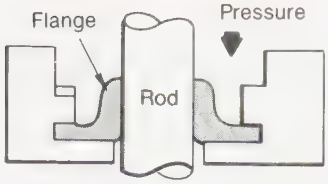
Cup seals are unbalanced, and seal only on the ID — usually at the heel, or shoulder. Cups are used in large volume for hydraulic and pneumatic service, and are available in leather, solid rubber, and fabric-reinforced rubber. Special formulations are available for difficult applications.



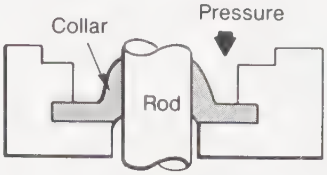
Cups used for low and variable pressures often need spring expanders that preload the cup walls. With reasonably high pressures, expanders are not needed.

One installation problem encountered with cups is excessive tightening of the inside follower. Excessive tightening crushes the bottom of the cup and causes poor sealing, high friction, and excessive wear. Some cups are made with extremely hard bottoms to combat excessive tightening.

Flange and collar seals are variations on the cup-seal design. They have developed a possibly unwarranted reputation for excessive wear and friction due to unbalanced operation. Flange and collar seals are widely used for sealing on shafts or pistons at moderate pressures, and because they are compact, they are typically used where there is insufficient space for a U-ring. They are generally considered to seal less efficiently than U-rings or V-rings.



FLANGE SEAL



COLLAR SEAL

Collar rings are very similar to flange rings, except for a slightly modified shape. Claimed advantage of the collar shape includes improved resistance to wear and scuffing.

Exclusion seals

Exclusion seals, wipers, and scrapers clean the surface of a retracting rod, removing abrasive particles such as dirt, mud, and ice. This protects the seal and extends service life. The importance of wipers cannot be overemphasized. Often a seal fails prematurely because the wiper wears out long before the primary seal. In such cases failure is not due to misapplication of the seal, but to the wiper not protecting the seal from abrasive wear.

Conventional rod wipers are usually produced from a material like high-quality polyurethane. They are designed to snap directly into the glands on common cylinders.

Typical properties for wiper materials are: hardness, 85-95 Shore A; tensile strength, 6,000 psi; elongation, 400%. They can typically be used in a temperature range from −40 to 210°F, although some manufacturers predict reduced life if the rods are exposed to steam and water over 190°F.

Sealing wipers are made with a sealing lip at the bottom and a rod wiper at the top, so that the wiper can perform as a pressure-energized lip seal inside the cylinder at the same time it wipes contaminants from the outside. The two most common types are a double-lip U-seal and a double-lip V-seal. Both are one-piece snap-in replacement seals that provide both sealing and wiping action.

Scrapers are exclusion seals that have a metallic lip or hard plastic scraping element to scrape heavy or tenacious materials from reciprocating

DESIGN CONSIDERATIONS FOR PTFE SEALS

The demand for more efficient engines and longer warranty periods has increased the use of PTFE as an oil-seal material. Despite their higher cost, PTFE seals generally are more cost effective because they provide long service life and better fluid compatibility, and withstand high shaft speeds and temperatures. PTFE has become a viable oil-seal material because of improvements in filler selections and advances in seal technology.

Fillers: The use of fillers compounded with PTFE is responsible for many of the excellent wear characteristics of the material. Fillers include glass fiber, graphite, MoS_2, carbon, and other inorganic and organic compounds. Almost any filler can be added to PTFE provided it can withstand the high sintering temperatures.

Most crankshaft seals presently are filled with glass fiber and MoS_2 or with graphite. The glass fiber serves as a wear deterrent under dry running and marginal lubrication; the MoS_2 aids lubrication during dry running. Glass-fiber-filled materials typically are used as excluder elements that reject dirt and dust in mobile applications. Because the fibers can be abrasive, a shaft hardness of 55 Rc is recommended.

Graphite-filled resins commonly are used in hydraulic-pressure sealing applications. The filler is somewhat softer and less abrasive; it also appears to provide a less porous seal surface, thereby decreasing possible fluid weepage.

Seal designs: The most common designs for PTFE seals center around what is termed a lay-down lip, which provides a broad contact width. The seal element starts as a wafer-shaped component with a center hole that is predetermined diameter smaller than the shaft diameter. In assembly, the element deforms conically with a broad surface exposed to the shaft.

The advent of the lay-down lip design has practically eliminated the need for a garter spring in PTFE hydrodynamic seals. The broad contact pattern forms a long, restricted orifice that blocks oil escape even under shaft misalignment.

However, a spring might be preferred in slow-speed applications, in pressurized applications where misalignment and runout are present, and in air-sealing applications. A certain amount of caution is in order especially if a fairly rigid seal element is used. Specifically, the temptation to use too heavy a spring must be avoided because a strong spring can promote high wear at elevated temperatures.

One particularly tough application is the sealing of dry or lightly lubricated air. Depending on allowable leakage and operating conditions, a spring-loaded PTFE seal could provide adequate sealing. However, a loaded lip can cause considerable wear at the shaft/seal interface.

It should be noted that PTFE is not a dead material. As it is formed on a tube, the dilated areas exhibit some memory caused by material elongation. The effect of this memory on dynamic sealing is not yet fully understood, but at high temperatures the element has a tendency to recover its flat-washer shape. This could account, in part, for the material's static sealing capability when the shaft stops rotating.

Shaft/seal relationship: The shaft must be considered as an integral part of the sealing system. Shaft parameters to be monitored include surface finish, hardness, surface roughness, geometry, and grinding/machining lead.

Common recommendations for PTFE seals include:

- Hardness should be held to 55 Rc minimum when possible. This applies to all pressure seals and most crankshaft seals. However, softer shafts can be used under certain conditions.
- Shaft finish usually is specified as 10 to 20 CLA, with a finer finish being acceptable. This is contrary to elastomeric seals, where too fine a finish cannot maintain a fluid film under the lip contact. PTFE seals have run successfully on rougher shafts — up to 24 CLA. A plunge-ground shaft is preferred, although any process that generates the specified finish without lead is acceptable.
- Maximum bore to shaft misalignment normally is 0.38 mm TIR, but this can be increased for larger seals.
- Maximum dynamic shaft runout also is 0.38 mm TIR. Again, higher runout can be handled depending on shaft speed and diameter.

shafts. The hard lip is kept sharpened by the honing action of the shaft. Wipers are sometimes used behind scrapers to catch any fine particles or fluids that pass the scraper.

There are two types of scrapers, conical scrapers and scraper rings. The conical scraper has a sharp knife edge that digs under the foreign matter and lifts it from the shaft. The scraper ring has a flat top, 1/32 to 1/16 in. wide. Although this produces somewhat more resistance to scraping than a knife edge, it has the advantage of extra strength.

The material of the scraping element must be tough enough to withstand the impact and abrasion of materials adhering tightly to the shaft. It must be resistant to corrosion, have low friction against the shaft material, and little tendency to score the shaft. Good spring characteristics are needed for conical scrapers.

Metals such as copper-silicon, aluminum, manganese bronze, beryllium-copper, and brass are most commonly used for scraping elements. For corrosion resistance, they may have cadmium or other platings.

Boots are used to keep undesired material from entering the seals of hydraulic cylinders and other fluid-power devices. Motion of the rod relative to the cylinder is absorbed by the flexing of the boot, so there is no frictional contact between stationary and moving elements, as with other seals.

Although many shapes of boots are commercially available, made to accommodate such devices as universal joints, shift levers, and hinges, specialized boots are designed particularly for hydraulic and pneumatic cylinders. They may be made of leather, plastics, elastomers, or occasionally of thin formed metal, although neoprene-coated nylon fabric is widely used for strength and resistance to abrasion. Leather tends to crack at low temperatures, but other materials can often be used over a range of −45 to 220°F. Special boot materials are available for high and low-temperature operation.

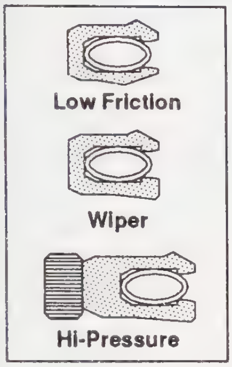
Boots are available to cover rod sizes from 0.5 to 10 in. diameter; because the boots are normally made to order, nearly any length is available. Typically, the minimum compressed length for a boot is 0.25 in. for the smallest rods; for some of the larger rods, minimum compressed length can be over 1 in.

Face seals

Mechanical face seals are a good choice when minimum leakage of the sealed fluid is the most important crite-

Spring Loaded Teflon® Seals

with the Patented Canted-Coil Spring



- ☐ -320 ~ 550°F
- ☐ Chemically Inert
- ☐ Ultra Low Friction
- ☐ 10^{-10} torr ~ 100k psi
- ☐ Sizes from 0.020 to 77"
- ☐ Free Design Assistance

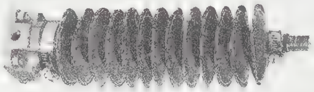
Call or send for
Free Samples and Catalogs:
Tel: 800-366-1006 or 714-557-5192
Fax: 714-241-0185

BAL SEAL
ENGINEERING COMPANY, INC.
620 WEST WARNER AVENUE, SANTA ANA, CALIFORNIA 92707-3398
®DuPont's trademark
U.S. patents: 4,655,462; 4,934,666

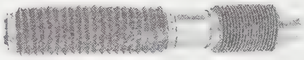
Circle 262

BELLOWS

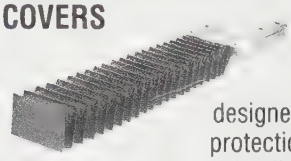
ROD COVERS



BALLBUSHING, SCREW AND SPLINE COVERS



LINEAR BEARING WAY COVERS



designed for protection of hydraulic and pneumatic cylinders . . . rotating screws and splines . . . linear bearing rails. Constructed of neoprene or elastomer coated fabrics without tooling charges.

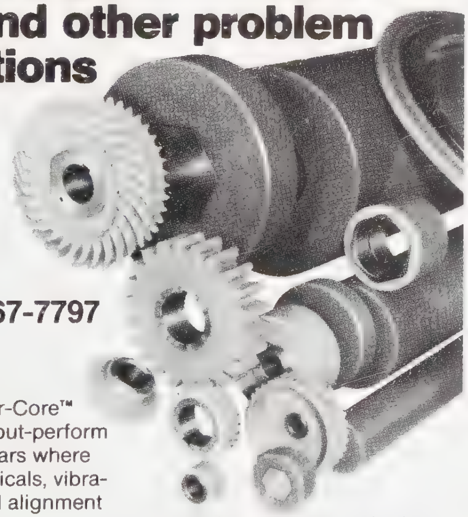
Request Bulletins RB-100, GW 200A

GORTITE ®
A & A Mfg. Co., Inc.
2300 S. Calhoun Rd.
New Berlin, WI 53151
414-786-1500

Circle 263

New gear material offers outstanding performance in noise and other problem applications

Free Durability Calculation Assistance FAX (201) 767-7797



New Intech Power-Core™ composite gears out-perform other available gears where noise, wear, chemicals, vibration, moisture and alignment problems exist.

A unique combination of Lauramid securely cast around a metal hub opens new alternatives for problem solutions and high torque applications (e.g. worm gears, spiral bevel gears, etc.).

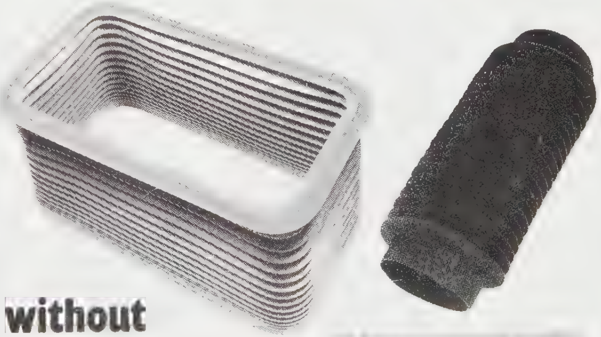
Satisfied customers who have replaced their steel gears report up to 12x longer gear life, often without lubrication!

Find out how Power-Core gears can help you. Call or write today for a test sample for your gear application.

INTECH **Power-Core**™
250 Herbert Ave., Closter, NJ 07624 TEL (201) 767-8066

Circle 264

Molded Bellows



without tooling charges

Gortiflex molded bellows are available in neoprene, silicone, butyl, viton, hypalon, buna-n and elastomer coated fabrics. Send us your bellows application and requirements . . . we'll custom design and fabricate to meet your needs, from concept to finished product, without expensive tooling charges.

write for Bulletin PR-100
GORTITE'
A and A Mfg. Co., Inc.
2300 S. Calhoun Rd.
New Berlin, WI 53151
414-786-1500

Circle 265

DYNAMIC SEALS

O-rings, common in static sealing situations, are frequently specified in light-duty dynamic applications (to 1,500 psi and 1 fps) because of their adequate performance at low cost. However, volume swell of the rubber (caused by fluid absorption) that is preferred in static applications, must be minimized for dynamic conditions.

T-rings, with backup rings on either side of the dynamic seal, resist tangential forces that can twist O-rings. However, the need for two backup rings means added cost. T-rings also exhibit a larger static side sealing length, resulting in better sealing. And because the backups are pressure energized, extrusion is less likely.

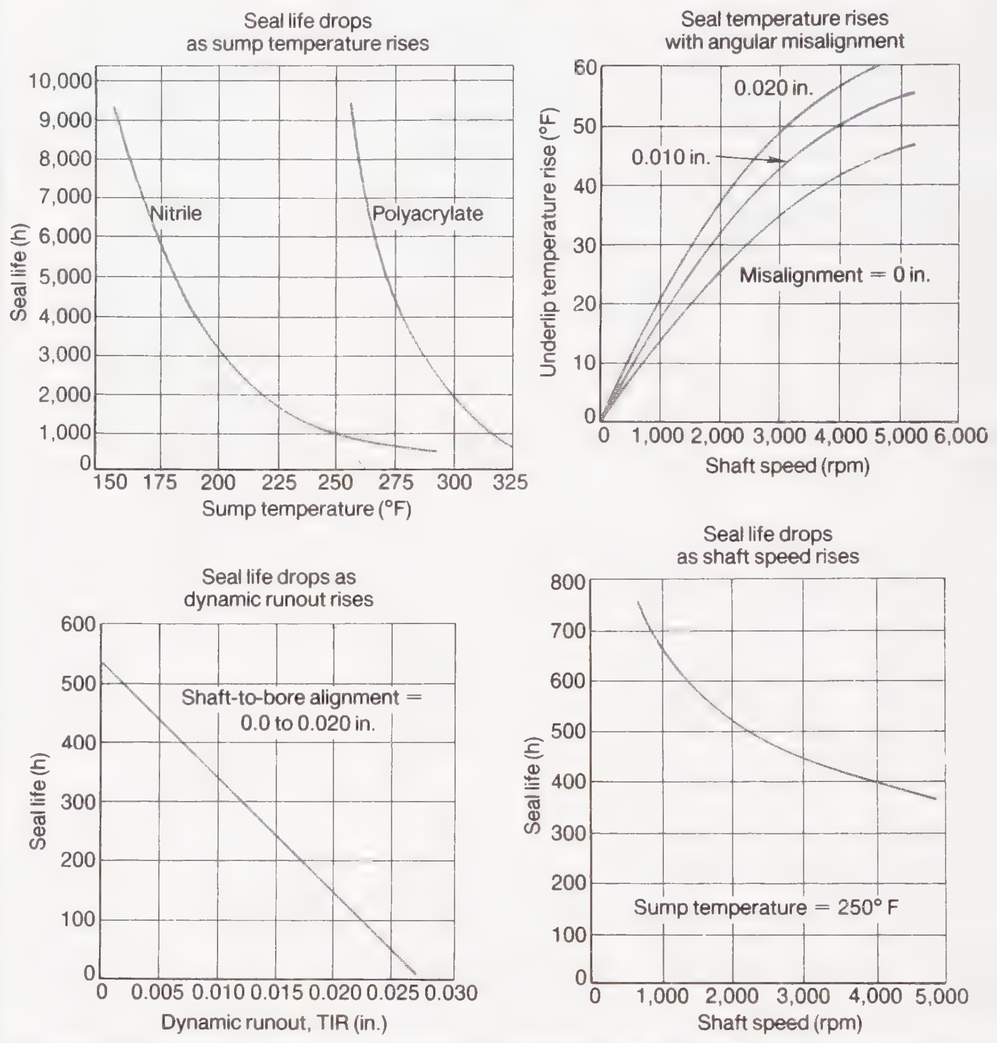
Asymmetrical U-cups are pressure-activated lip seals with different lip profiles for sealing dynamic and static surfaces. They are usually not adequate for low-pressure sealing. Symmetrical U-cups, while not as effective, are widely used because of their lower cost, and can be used as either a piston or rod seal.

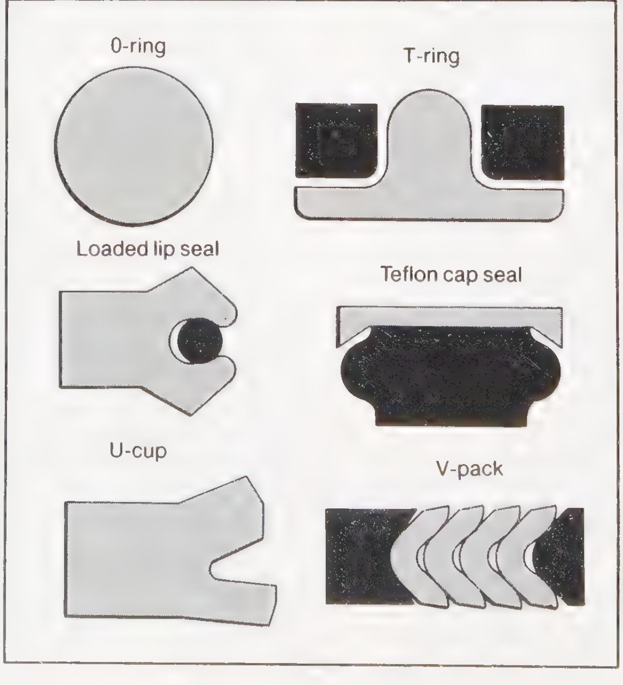
An O-ring-loaded urethane lip seal is a good low and high-pressure seal with very good wear characteristics. Urethane exhibits excellent abrasion and tear resistance, but has poor compression set characteristics. Adding a rubber O-ring provides the compressive sealing force needed at low pressure; however, this slightly increases seal cost. At high pressure the seal acts like a U-cup.

When high velocities may cause frictional heat buildup, an elastomer-activated PTFE-capped piston seal is required. This is merely a compression seal with a Teflon cap. PTFE has a low coefficient of friction and excellent wear characteristics. In fact, it is capable of sealing for millions of cycles, but PTFE does not seal as well as rubber and is susceptible to damage from solid contaminants.

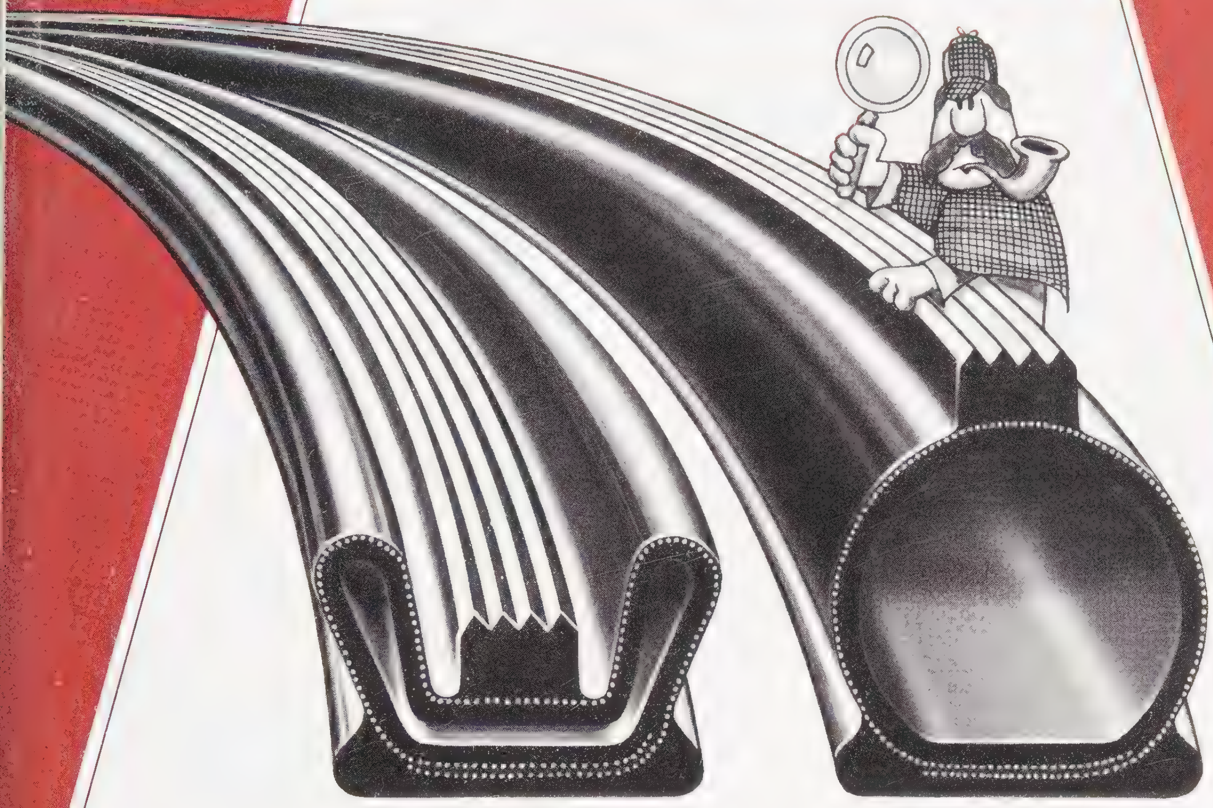
V-packs are pressure-energized lip seals that provide the advantage of multiple sealing lips. However, a small amount of leakage must be allowed, to provide a lubrication film between the metal and rubber of the furthest sealing lips. Otherwise, the seal will "run dry" and be destroyed by heat buildup. For zero low-pressure leakage, a urethane vee should be inserted as the last (outer) member of the vee stack.

HOW OPERATING CONDITIONS AFFECT SEAL LIFE





WE CLOSE GAPS...

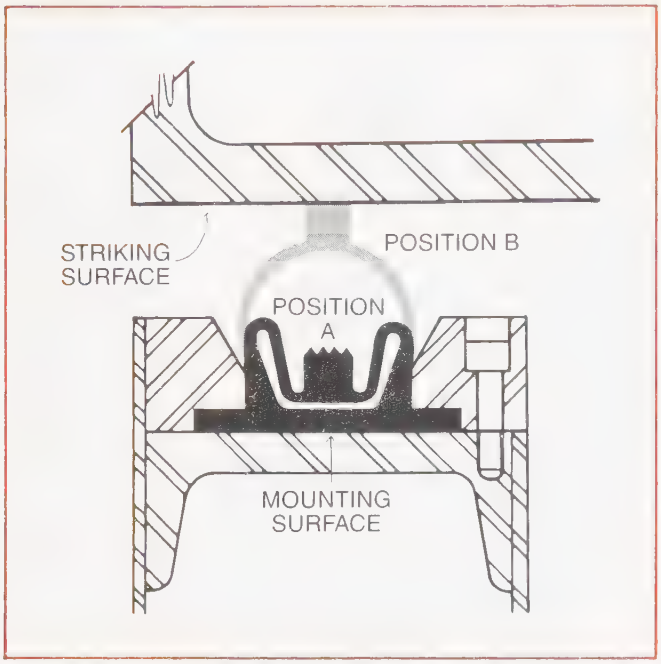


SEAL MASTER
INFLATABLE
SEALS

Circle 266

What is an Inflatable Seal?

An inflatable seal is a fabric-reinforced elastomeric tube custom molded in a concave, convoluted or flat configuration. It is designed to round out with the introduction of an inflation medium to form a tight barrier between a mounting and striking surface. For example, see the cross section illustration below. Position A shows the molded configuration and Position B depicts the inflated configuration.



How Does an Inflatable Seal Work?

Upon introduction of the inflation medium, it quickly expands to the striking surface, effecting a positive seal. When the inflation medium is removed, the seal retracts immediately and naturally to the deflated "memorized" configuration. This position provides clearance for free movement of one or both surfaces.

How is an Inflatable Seal Inflated?

The most common inflation medium is regulated air. The specific parameters of the application determine the optimum operating pressure. In some applications, liquid or gel may be used as the inflation medium. Introduction of the inflation medium is through a stem which is usually a flexible hose secured to an integrally molded fitting with a ferrule. Smaller seals are usually supplied with a 3/16" I.D. hose. Larger seals usually have a 3/8" I.D. hose. A variety of fittings may be attached to the end of the hose (for example, see the illustration entitled "Radially in").

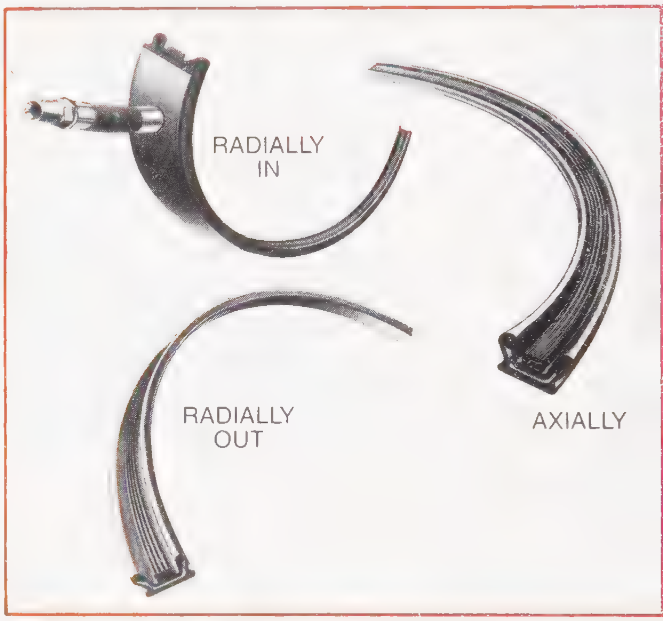
Where are Inflatable Seals Used?

Inflatable seals are used virtually anywhere a positive seal is needed between two opposing surfaces. Seal Master Inflatable Seals are being used successfully in the following industries: Aerospace–Aircraft–Appliances–Architectural–Automotive–Chemical–Construction–Electric power–Electronics–Fabricated metal–Farm equipment–Food processing–Government agencies–Laundry–Lumber–Marine–Medical–Military–Mining–Nuclear–Paper–Petroleum–Pharmaceutical–Rubber–Steel–Telecommunications–Textiles–Transportation–Utilities–Waste disposal.

More specifically, Seal Master Inflatable Seals are being used on doors, windows, canopies, gates, hatches, containers, chambers, valves, bins, plugs, shafts, conveyors, attenuation devices, cushioning devices, clamping devices, actuating devices and test equipment.

What Geometry will an Inflatable Seal Conform To?

Inflatable seals can be installed in three different planes; radially in, radially out and axially. They are made in strips with closed ends or in continuous loops. They will conform to many different contours. The bend radii will vary from seal to seal and if a very sharp and/or mitered corner is necessary, the seal can be specially molded to the exact configuration. This versatility allows Seal Master Inflatable Seals to be used in many different applications.



Why use an Inflatable Seal?

An inflatable seal has several advantages over more conventional sealing methods. (1) It provides a pressure tight closure. (2) It simplifies the design of structure and hardware. (3) It minimizes the need for close machining and/or fabricating tolerances.

Some Seal Master Inflatable Seal Materials

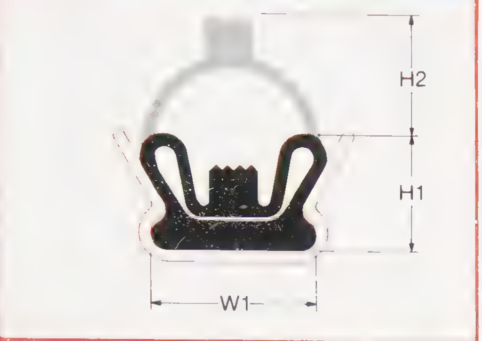
Considering the wide variety of applications, Seal Master uses several elastomers including: Natural rubber, Chloroprene (Neoprene), Nitrile (Buna N), Butyl, Silicone, Ethylene propylene, Epichlorohydrin, Flourinated hydrocarbon (Viton), Styrene butadiene (Buna S) and Polyurethane. Strength and structural integrity are provided by a variety of reinforcing fabrics, including Dacron, Kevlar, Nomex and Nylon.

Some Inflatable Seal Mounting Methods

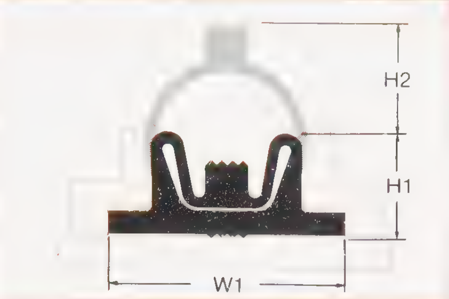
Many methods of mounting are employed. The red lines in the illustrations, right, indicate some of the more common ones. The method used must hold the seal in place, must allow it freedom to inflate and deflate and should protect it from damage.

Some Seal Master Inflatable Seal Types

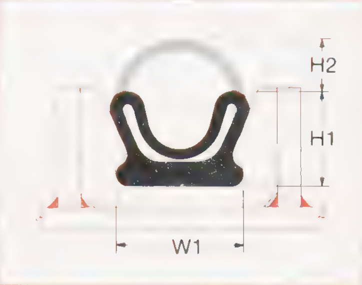
The cross sections shown below are typical inflatable seal designs. Particular sizes and shapes are identified by the listed code letters. Please note that the seals will compensate for variation in the gap up to the maximums indicated by the H2 dimensions.



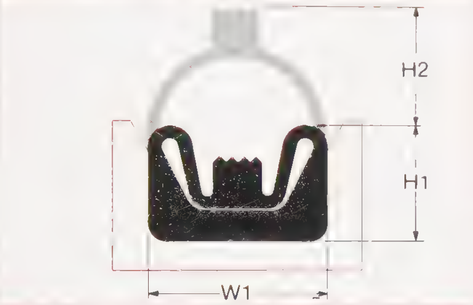
CODE	W1	H1	H2
G-1	.88	60	65
G-2	.88	50	.50
G-5	.69	.50	.50
G-8	63	.50	35
G-12	1.75	1.20	1 30
G-14	.88	31	.25
G-15	.56	.38	38
G-21	3.06	2 13	2.25
G-31	75	.63	.63
G-32	.75	.44	.44



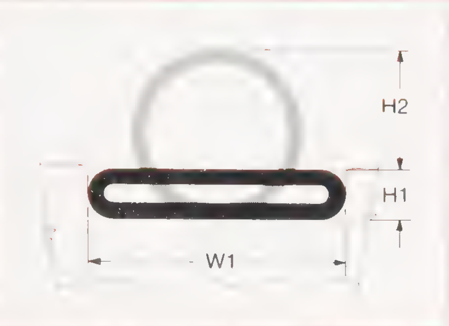
CODE	W1	H1	H2
G-9	2.75	1.50	1.43
G-11	3.63	2.00	1.75
G-16	5.88	1.25	.75
G-17	5.38	1.25	.75
G-18	3.88	1.25	.75



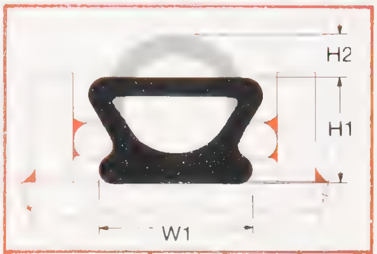
CODE	W1	H1	H2
G-25	63	50	25
G-26	.68	50	25
G-27	.88	50	25
G-28	.88	60	35
G-29	1 75	1.20	.85
G-30	.56	.38	18



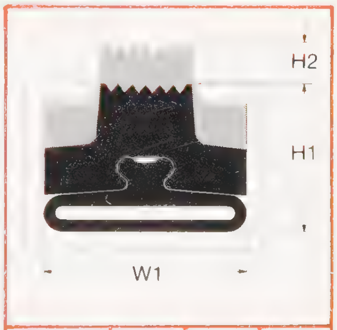
CODE	W1	H1	H2
G-3	.54	.44	.44
G-4	.69	.46	.54
G-7	88	.56	.44
G-10	1.75	1.38	1.25
G-22	1.25	1.13	1.00
G-34	2.00	1.00	.78



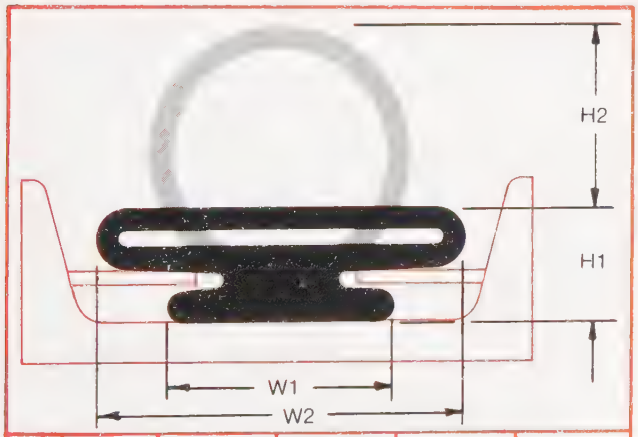
CODE	W1	H1	H2
P-6	1 50	.50	50
P-7	2.00	50	63
P-8	2.25	75	75
P-13	6.00	1 50	2.50
P-14	94	31	.19
P-15	3.00	75	1.00
P-20	3 25	50	1 25
P-21	4 00	50	1 75
P-24	1 25	38	25



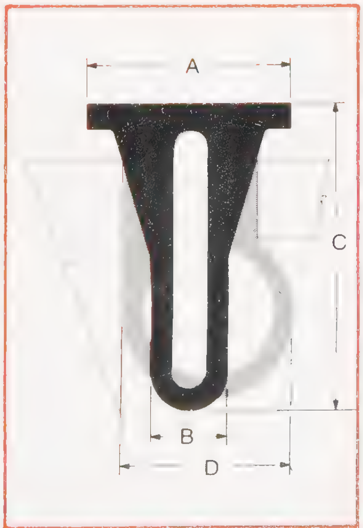
CODE	W1	H1	H2
G-13	88	.60	20
G-24	88	50	.20



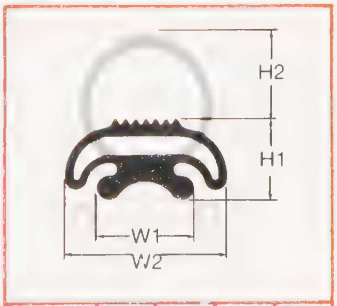
CODE	W1	H1	H2
S-1	1.38	1.00	.28
S-2	2.00	1.00	.44
S-3	2.75	.88	.81



CODE	W1	W2	H1	H2
P-1	1.00	1.25	.63	.38
P-2	1.75	2.00	.88	.75
P-3	2.00	3.25	1.00	1.63
P-4	3.25	4.00	1.13	2.00
P-10	4.25	7.25	2.06	3.00
P-22	3.00	4.00	1.63	1.75
P-23	.75	1.00	.50	.31
P-26	5.00	9.00	2.38	4.00
P-30	2.00	3.00	1.25	1.25
P-50	3.25	5.00	1.25	2.63



CODE	A	B	C	D
P-5	4.00	.50	6 50	3 50
P-25	2 00	75	3 60	1 75



CODE	W1	W2	H1	H2
G-6	.75	1 25	63	68
G-23	50	1 13	44	50

Circle 266

Custom Solutions by Seal Master

Seal Master recognizes the uniqueness of each customer's application and is qualified to provide design assistance—on new applications or to troubleshoot old sealing problems. Today, over 1,800 distinctly different types of products sold worldwide testify to Seal Master's ability to "zero in" on the best solution.

Design Requirements

Seal Master will be able to recommend the best possible solution if all pertinent information is provided. Specifically, please answer the following:

- What is being sealed
- Dimensions of gap to be sealed
- Length of seal required
- Seal to be strip or continuous loop
- Surrounding environment
- Pressures across seal
- Is inflation radially in, out or axially
- Temperature range (– 100°F to + 600°F)
- Method of mounting
- Inflation source
- Are controls required

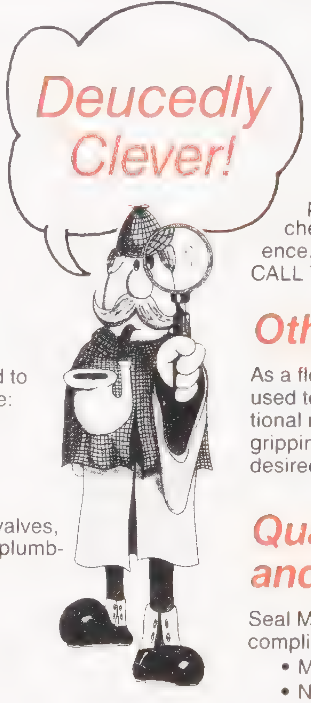
Accessory Products

Seal Master offers accessory products designed to facilitate the use of inflatable seals. They include:

- Extruded aluminum retainers
- Extruded and molded rubber retainers
- Machined metal retainers
- Fasteners
- Inflation control devices, including boxes, valves, regulators, gauges, alarms, compressors, plumbing fittings and hose

Non-Inflatable Products

- Compression Seals
- Covers
- Diaphragms
- Gaskets


Deucedly Clever!

Seal Master Offers More Inflatable Seal Experience than Anyone

The Seal Master team includes individuals who were instrumental in the pioneering and development of inflatable seals as far back as the 1940's.

Throughout the '50's, '60's and early '70's, these specialists continued to refine their craft in rubber technology and specialized products under the employ of major concerns in the rubber industry.

These talents were brought together in 1974 with the formation of Seal Master Corporation.

Since that time, Seal Master has advanced the state of the art through the introduction of new products and innovations which have been described as "deucedly clever."

If you are considering a new design, or experiencing a problem sealing: heat/cold, light/dark, pressure/vacuum, chemicals, radiation, contaminates, radio frequency interference, electromagnetic interference, noise, water or weather, CALL THE SPECIALISTS — CALL SEAL MASTER.

Other Products

As a flexible pressure vessel, Seal Master Inflatable Seals are used to apply forces that would not be possible using conventional rigid methods. This principle can be used with actuators, gripping devices, lifters and where force applications are desired.

Quality Assurance and Quality Control

Seal Master maintains a formal Quality Assurance program in compliance with the following standards:

- Military —MIL I 45208
- Nuclear —NQA 1 (USA)
  —Z299.3 (Canada)

All materials used by Seal Master are laboratory tested. All products are inspected and tested a minimum of two times prior to shipment. Functional testing is performed as required.

A Partial List of Customers Who Have Closed the Gap with Seal Master Inflatable Seals

ABBOTT LABORATORIES
AEROJET
ALLIS CHALMERS
ALCOA
AMERICAN STERILIZER
ARMOUR FOOD COMPANY
ARMSTRONG WORLD INDUSTRIES
BABCOCK & WILCOX
BAY SHIPBUILDING
BECHTEL POWER CORP.
BELOIT CORP
BETHLEHEM STEEL CORP
BOEING COMPANY
BOISE CASCADE
CANADAIR
CAROLINA POWER & LIGHT
CATERPILLAR
CHICAGO BRIDGE & IRON
CHRYSLER CORPORATION
COMBUSTION ENGINEERING
DOW CHEMICAL
E. I. DUPONT
EASTMAN KODAK
E. G. & G.
FLORIDA POWER & LIGHT
FORD MOTOR COMPANY
GENERAL DYNAMICS
GENERAL ELECTRIC
GENERAL FOODS
GENERAL MOTORS
B. F. GOODRICH
GOODYEAR TIRE & RUBBER
HEWLETT PACKARD
HUGHES AIRCRAFT
IBM CORPORATION
INGERSOLL RAND
JOY MANUFACTURING
KIMBERLY CLARK
LOCKHEED
3M
MARTIN MARIETTA
MCDONNELL DOUGLASS
MICHELIN TIRE
MORTON THIOKOL
NASA
OVERLY MANUFACTURING
ONTARIO HYDRO
PAN AMERICAN WORLD SERVICES
ROCKWELL INTERNATIONAL
PRATT & WHITNEY
SCHLUMBERGER
SWIFT ECKRICH
TVA
U. S. AIR FORCE
U. S. ARMY
U. S. MARINE CORPS
U. S. NAVY
UNION CARBIDE
USX CORPORATION
UTAH POWER & LIGHT
WESTINGHOUSE ELECTRIC
WEYERHAEUSER PAPER COMPANY

SEAL MASTER EXPORTS WORLDWIDE

SEAL MASTER CORPORATION

CONSULTANTS • DESIGNERS • MANUFACTURERS OF INFLATABLE SEALS AND CUSTOM RUBBER PRODUCTS
368 MARTINEL DRIVE, KENT, OH 44240-4369 USA • (216) 673-8410 FAX (216) 673-8242

Circle 266

rion. The primary sealing interface is between rotating and stationary members that form a plane perpendicular to the shaft. The sealing area is a narrow ring where the two faces contact. One of the sealing faces is usually metal or ceramic, and the other is usually graphite or plastic.

To keep precision seal faces closed in the absence of hydraulic pressure, some form of loading device, usually a spring, is needed. Loading should be high enough to overcome friction and keep the faces closed under all operating conditions, but unnecessarily high loading will tend to shorten the useful life of the seal. The most common device for supplying a loading force to the seal face is a helical spring. But multiple helical springs, wave springs, bellows, and rubber elements are also used.

Standard face seals have been used for pressures up to 3,000 psi, rotating speeds up to 50,000 rpm, and temperatures from −425 to 1,200°F. Special face seals have been developed for pressures up to 10,000 psi. For extremely high pressures, two or more face seals can be lined up in tandem, splitting the pressure differential equally.

Mechanical face seals usually cost more than radial oil seals or compression packings. However, the elimination of shaft wear may in some applications justify the increased cost.

Face seals usually take about the same space as packings, but substantially more room than radial seals. However, special face seals that take less space than conventional face seals are available.

All face seals, because of their design configurations, tolerate only limited axial motion between shaft and housing. Thus, they cannot be used for long stroke, reciprocating-shaft applications.

Another disadvantage of face seals is their precision. Face flatnesses of 11.6 μin. and surface finishes of 2 μin. are not uncommon, and the seals must be manufactured to cleanliness standards similar to those in the precision-bearing industry. As with most precision devices, rough or careless handling must be avoided.

Compared to other types of dynamic seals, face seals have longer life and can reduce warranty and liability cost, downtime, and leakage. In addition, face seals are easy to sterilize and eliminate system contamination by packing fragments.

Unbalanced face seals act like pistons. Fluid pressure from one direction loads the primary seal ring and mating ring against each other. Pressure from the opposite direction unloads — and may even separate — the rings. The result is either unnecessarily high friction, wear, heat generation, and power waste or else high leakage when the faces separate.

Pressure balancing reduces the piston action, keeping contact load closer to the minimum for effective sealing and enabling the seal to stand larger pressure reversals.

Unfortunately, there are also disadvantages to balanced seals. They typically cost 10 to 50% more than unbalanced seals for the same application because of closer tolerances and more complex seal shapes. They are subject to catastrophic failure if operating conditions do not closely match design conditions. And they usually require more space than unbalanced seals. Therefore, unbalanced seals are used whenever their frictional and pressure-reversal characteristics are acceptable.

Felt seals

Unlike lip seals and squeeze packings, felt seals require relative little shaft

TIME PROVEN
Spring-Energized Seals

- *Wear-resistant Turcite PTFE seal compounds*
- *Low friction and non-aging*
- *Vacuum to 30,000 psi*
- *Standard, metric and custom sizes and designs*
- *Precise seal loading with any of three spring designs*

Designed for long term reliable sealing, Variseals are made of chemically inert Turcite® compounds. With corrosion-resistant Stainless Steel, Hastelloy® or Elgiloy® springs, Variseals are immune to compression set and heat aging to 575°F. Self-lubricating materials extend seal life in dry and poorly lubricated conditions. *For catalogs and technical support, call* **1-800-466-1727.**

American Variseal
P.O. Box 1479
510 Burbank Street
Broomfield, Colorado 80038
Fax: 303-469-4874

SHAMBAN

Circle 267

pressure to function effectively. They are commonly used near ball and roller bearings as lubricant retainers. Advantages of felts seals include:

Chemical resistance: Wool felt resists dilute mineral-acid solutions, unless continuously saturated and intermittently dried. It is damaged by alkalis. Untreated, it resists oil, greases, waxes, and most solvents. Mechanically interlocked synthetic-fiber felt seals withstand attack by strong acids and bases, and are stable in water, common fuels, lubricants, hydraulic fluids, and solvents.

Filtration: Wool felt seals, in a dry state, are highly effective as filters in removing particles of 0.7-micron size and larger. When saturated in lubricants, even smaller particles are trapped and retained.

Oil wicking: Capillary properties of a felt seal ensure lubrication after long idle periods.

Oil absorption: Storage capacity is largely a function of density. However, about 78% of the volume of a felt seal serves as oil storage.

Shaft speeds: Top speed for felt seals is usually 2,000 fpm. There are applications operating at speeds as high as 4,000 fpm, where shafts are hard and smooth and where ample lubrication is present in the seal.

Low friction: The coefficient of friction averages 0.22 for dry felt against steel and is substantially reduced when felt is presaturated with oil.

Temperature limit: The usual temperature limits of felt seals are −60 to 250°F. However, synthetic-fiber felts offer a wide range of strength and chemical resistance at temperatures up to 400°F.

Felt seals are manufactured in two general types: plain and laminated.

Plain felt seal are precision-cut washers fabricated from standard grades of felt. They are usually presaturated with lubricants of slightly greater viscosity than that used in the bearing. Plain felt seals afford positive bearing protection and provide a reservoir for lubricant storage — making it available as needed. If run dry, they protect and polish rather than score a shaft. They seldom fail through aging, embrittlement, or disintegration. At temperatures from −60 to 250°F and operating speeds up to 2,000 fpm, plain felt seals are highly economical and require replacement only when the machines in which they are used are overhauled. These seals should not be used with oils of extremely low viscosity or to retain pressurized lubricants. For these applications, laminated or impregnated felt should be considered.

Laminated felt seals are made by combining grades of felt with layers of impervious elastomer. This sandwich construction permits use of two or more felt grades or densities in one seal; one grade for oil retention and a second for dust exclusion. The impervious layers of oil-resistant elastomer also stop leakage of low-viscosity liquids through the felt.

To meet special requirements, either style can be impregnated with one of several materials. Paraffin, petroleum, or colloidal graphite increases the resistance of basic felt to water and mud, improves its resistance to pressurized lubricants, and lowers its coefficient of friction.

Radial lip seals

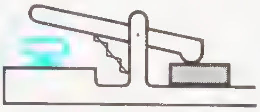
Radial lip seals, also know as oil or shaft seals, are primarily used for retaining lubricants in equipment having rotating or oscillating shafts. The seals are relatively inexpensive, take little

Our well-known
PNEUMA-SEAL®
Inflatables aren't just for sealing

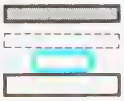
Other applications include:

CLAMPS
to secure a workpiece to a table; or to assemble components with adhesives or epoxies

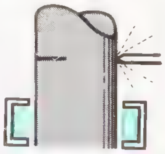
ACTUATORS
instead of bulky cylinders and other complex mechanical devices



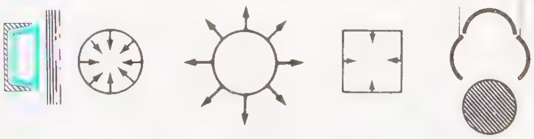
LIFTERS
to raise objects or assemblies-even very heavy ones-uniformly



CHUCKS / HOLDERS
to grip objects tightly and resist torque or other loads during machining / manufacturing processes



GRIPS
Pneuma-Grip® Rings or other regular shapes to grip cylinders, cones, spheres, blocks for lifting, upending and rotating


expand in and grip on OD
expand out and grip ID
expand in and grip flat sides
wrap around & expand in

Give us your problem. We custom design and fabricate to your needs. For engineering assistance or to have a Presray representative contact you, call us at any of the following telephone numbers:

(914) 855-1220 Telex: 646720
FAX: (914) 855-1139 West Coast: (714) 751-2993

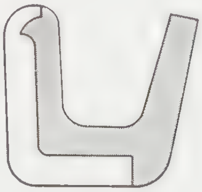
PRESRAY
Presray Corp., 159 Charles Colman Blvd., Pawling, NY 12564

YOU MAY ALSO CONTACT US BY CIRCLING THE APPROPRIATE RESPONSE NUMBER INDICATED BELOW.

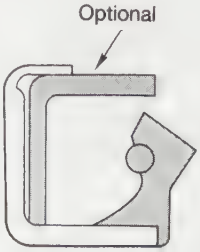
space, install easily, and can handle many types of sealing situations. They can be used with most oils and hydraulic fluids at moderate pressures over wide temperature ranges, and are tolerant of misalignment, dynamic shaft runout, and variations in shaft speed.

TYPES OF RADIAL LIP SEALS

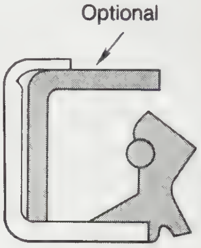
There has been a tendency to standardize three basic types of lip seals: single-lip unloaded, single-lip spring loaded, and double-lip spring loaded. Single-lip unloaded seals are typically used for greases or viscous fluids, and are relatively inexpensive. Single-lip spring-loaded seals are intended for general sealing purposes and for high-speed grease retention. An optional inner case improves structural rigidity. Double-lip spring-loaded seals are preferred to single-lip seals when dust and dirt must be excluded from the sealed cavity. Again, optional inner cases improve rigidity.



SINGLE-LIP
UNLOADED



SINGLE-LIP
SPRING-LOADED



DOUBLE-LIP
SPRING-LOADED

Operating procedures

In most lip seals, increasing fluid pressure increases lip-contact pressure. In a properly designed and installed seal, the lip rides on a thin film of lubricant. Because the film does the sealing, its thickness (usually about 0.1 mil) must be controlled precisely by the mechanical pressure of the seal element and the shaft finish. If the film gets too thick, fluid leaks. If too thin, the lip wears, friction increases, and stick-slip oscillations can result. Stick-slip oscillations cause a surface wave in the seal, which permits leakage.

Aside from mechanical pressure, the main factors affecting film thickness are sealed pressure and temperature. In most seals, as sealed pressure increases, lip contact pressure increases, reducing film thickness. Increasing temperature (which may stem from increasing shaft speed) reduces viscosity and, hence, film thickness. As the film gets thinner, friction increases, temperature increases, and film thickness continues to decrease. If this cycle continues, it can lead to seal failure. Maximum permissible pressure for radial lip seals range from 7 psi for shaft speeds below 1,000 fpm to 3 psi for shaft speeds above 2,000 fpm.

Although elastomeric lips can provide a constant shaft pressure under a given set of operating conditions, they are sensitive to pressure and temperature changes in the sealed fluid, and they tend to become harder with age. Therefore, a garter or finger spring is usually included in the seal assembly to maintain the desired shaft-contact pressure.

Shaft condition also has a profound effect on sealing. Shafts should generally be hardened to at least R_c 30, and should have a surface finish of 10 to 20 μin. Finishes finer than 10 μin. show no improvement in seal life, and some laboratory evidence indicates that finishes of 2 μin. or finer can shorten seal life because they cannot support an oil film. Finishes without spiral lead are preferred, but if lead is present, it should tend to guide the sealed fluid inward.

Correct shaft diameter is also important. An oversize shaft causes the seal lip to exert too much pressure; undersize shafts result in too little pressure. Overpressure leads to early failure, and underpressure promotes leakage. Recommended tolerances range from ±0.003 in. for 4-in. diameter shafts to ±0.01 in. for shafts with 10-in. diameters and larger.

Axial face seals

The function of an axial face seal, like felt radial seals, is to protect bearings from contaminants. It functions on a rotating or stationary shaft, but not an oscillating one.

Rubber rotary-shaft axial face seals provide a contact seal to keep dirt, dust, and moisture from bearings and critical machine parts. A flexible lip is tolerant of angular misalignment, eccentricity, axial movement, yet produces lower friction than other contact-seal designs.

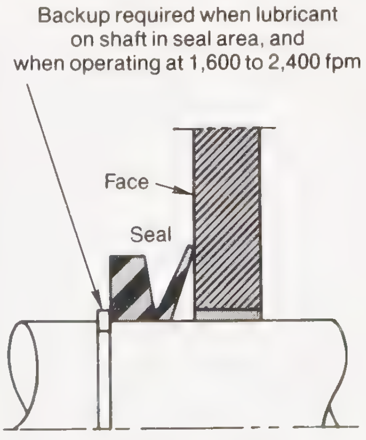
The rotary-shaft axial face seal can be used as a primary seal for grease and oil, and against water splash, dirt, and other contaminants. In addition, it can

SEAL LIFE

Radial lip seal life is determined by its ability to maintain a constant radial force between sealing element and shaft. Anything detrimental to that condition shortens seal life and effectiveness. Hardening or softening of the rubber lip is the most common cause of failure.

Sealing is generally based on line contact between seal and shaft. Anything causing rapid wear of the sealing lip decreases radial pressure by increasing contact area. Seal wear is caused by shaft irregularities, lack of lubrication, excessive frictional heat, and excessively soft sealing elements.

Long life is considered to be more than 1,000 h. Barring catastrophic failure, seal deterioration begins as subtle, gradual changes in organic structure. Frequently induced by oxidation by-products of the lubricant, these changes impair the element's elasticity. Then the element cannot follow the minute displacement of the shaft, and leakage results.

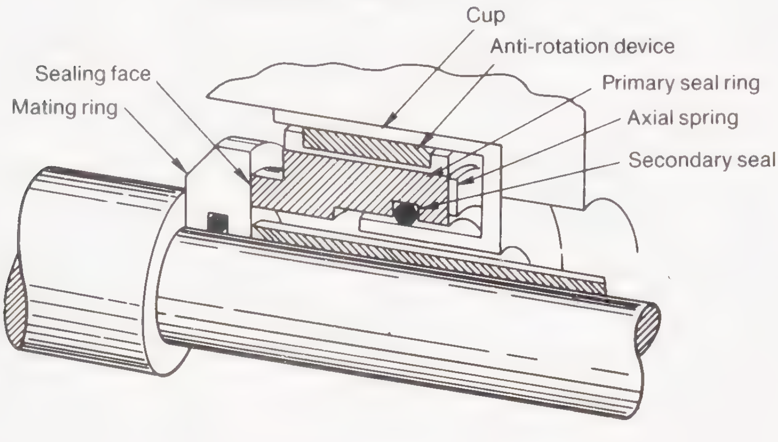

Backup required when lubricant
on shaft in seal area, and
when operating at 1,600 to 2,400 fpm
Face
Seal

ROTATING SHAFT

SEAL TEMPERATURES

Seal temperatures have a substantial influence on leakage because of their effect on fluid viscosity and material expansion or contraction. Temperature limits shown in the table represent seal surface temperatures, which may be higher than ambient fluid temperatures, particularly in high-speed applications.

FACE SEAL NOMENCLATURE



Temperature limits for materials and surface treatments

Material	Temperature (°F)
Low-alloy gray irons	650
Malleable iron	700
Ductile iron	700
Ni Resist	800
Ductile Ni Resist	1,000
410 stainless steel	900
17-4 PH stainless steel	900
Bronze	600
Stellite #31	1,200
Inconel X	1,250
Tool steel, Rc 62-65	900
Carbon (high temp.)	950
Filled Teflons	450 to 500
Glass-filled Nylon	350 to 400
S-Monel	950
Polyimide	750

Surface treatment	Temperature (°F)
Chromium plate	500
Tin plate	700
Silver plate	600
Cadmium-nickel plate	1,000
Flame Plate LW1	1,000
Flame Plate LC-1A	1,300
Flame Plate LA-2	1,300

be used as an auxiliary dirt seal to protect other radial-lip seals.

One proprietary axial face seal is a one-piece ring of molded polymer. Slight undersizing of the seal ID allows it to constrict, holding it in place on the shaft. The sealing lip contacts the axial face to keep contaminants from protected machine parts. Up to about 1,600 fpm, no backup is required. From 1,600 to 2,400 fpm, a backup ring on the shaft is needed when the seal operates in the presence of lubricants. From 2,400 to 3,000 rpm, radial support is required to maintain constriction to the shaft. Above 3,000 fpm, centrifugal force may lift the finger away from the axial face. In this case, the seal should be mounted stationary so that only the axial face rotates. Seal contact speeds are then possible to 20,000 fpm.

Selection factors for seals

The primary factors affecting seal selection are temperature, wear resistance, abrasion, sealed pressure, face materials, vibration, and expected life. Usually, bellow seals are needed for high-temperature applications.

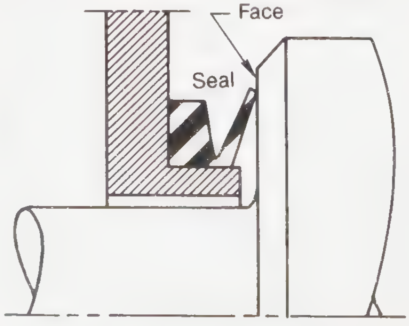
Temperature affects all seal materials, but its most important effects are on the secondary seals. The general limitation on temperature for standard synthetics is about 225°F although some are available for uses up to 600°F. PTFE can be used over a temperature range of −400 to 550°F, although most manufacturers rate PTFE seals on the basis of 500°F maximum temperature.

Asbestos elements have been used up to 650°F. Above 650°F, metal bellows, U-cups, or piston rings can be used, but these seals are considered specials.

Lubrication can reduce heat generation at the seal interface, but care must be taken to prevent coking. Direct cooling with a cooling chamber and heat exchanger can help control thermal problems. In this method, an integral pumping ring on the rotating seal element circulates coolant through an inner chamber in the stuffing box.

Wear resistance depends largely on temperature and chemical factors, and on abrasives. To minimize wear, the sealed fluid should be a good lubricant for the materials of the seal head and seat. Furthermore, all seal materials should be virtually impervious to corrosion by the sealed fluid.

Face materials subject to dry running because of malfunctioning equipment can fail prematurely. Double seals with isolated liquid circulation avoid this hazard. For systems with external circulation, pressure drops can be detected with a pressure-sensitive switch.



STATIONARY SHAFT

Abrasion is the bane of face seals. Faces should be cleaned before initial start-up to prevent premature failures. With liquids that form abrasives on contact with air, a buffer zone or quench gland should be provided between the atmosphere and the seal faces. With liquids that form abrasives at certain temperatures, heating or cooling is necessary to dissolve abrasives near the seal faces. With liquids that are inherently abrasive, a neutral clean liquid can sometimes be injected into the seal chamber. If the sealed liquid cannot be contaminated, a double-seal design can be used, or a centrifugal separator should be inserted ahead of the seal.

High sealed pressure can drastically shorten the life of the sealing faces, and should be compensated by seal balancing.

Face materials must be compatible with each other and with the sealed fluid. Because of their good mechanical and thermal properties, graphites are generally used as one of the primary sealing elements. The opposing element can be made of ceramics, iron, bronze, stainless steel, tool steel, and various other metals plated with dense chrome. The ceramics are some of the hardest face materials available and have excellent wear and corrosion properties. However, they cannot stand tensile stress and are subject to cracking by thermal shock.

Vibration can shorten the life of a seal, particularly if imposed vibration during operation has a frequency near the natural frequency of the seal. The basic precaution is to ensure that the seal's natural frequency is higher than the highest imposed frequency. This precaution is particularly necessary with metal bellows.

Life expectancy depends on both shelf life and operational life. The shelf life of metal bellows is practically unlimited, whereas organic secondary seals may have shorter shelf life, particularly at elevated temperatures. Within their temperature limits, elastomeric bellows have better operational life than metal bellows. However, metals withstand higher temperatures.

Compression packings for various service conditions

			Service condition	
Fluid Medium	**Reciprocating shafts**	**Rotating shafts**	**pistons or cylinders**	**Valve stems**
Acids and caustics	Asbestos Metallic Plastic (pliable) PTFE Flexible graphite	Asbestos Asbestos-PTFE Plastic (pliable) PTFE Graphite yarn Flexible graphite	PTFE	Asbestos Plastic (pliable) PTFE Graphite yarn Flexible graphite
Air	Asbestos Metallic Plastic (pliable) Flexible graphite	Asbestos Asbestos-PTFE Plastic (pliable) Flexible graphite	Leather Metallic	Asbestos Plastic (pliable) Flexible graphite
Ammonia	Duck and rubber Metallic Flexible graphite	Asbestos Asbestos-PTFE Flexible graphite	Duck and rubber	Asbestos Duck and rubber Flexible graphite
Gas	Asbestos Metallic	Asbestos Asbestos-PTFE Flexible graphite	Leather Metallic	Asbestos Flexible graphite
Cold gasoline and oils	Asbestos Plastic (pliable) Flexible graphite	Asbestos Asbestos-PTFE Plastic (pliable) Flexible graphite	Leather	Asbestos Plastic (pliable) Flexible graphite
Hot gasoline and oils	Asbestos Plastic (pliable) Flexible graphite	Asbestos Asbestos-PTFE Plastic (pliable) Graphite yarn Flexible graphite		Asbestos Plastic (pliable) Graphite yarn Flexible graphite
Low pressure steam	Asbestos Duck and rubber Metallic Plastic (pliable) Flexible graphite	Asbestos Asbestos-PTFE Metallic Plastic (pliable) Flexible graphite	Duck and rubber Metallic	Asbestos Duck and rubber Plastic (pliable) Flexible graphite
High pressure steam	Asbestos Metallic Plastic (pliable) Flexible graphite	Asbestos Asbestos-PTFE Metallic Plastic (pliable) Flexible graphite	Metallic	Asbestos Metallic Plastic (pliable) Flexible graphite
Cold water	Duck and rubber Flax, jute or ramie Leather Plastic (pliable) Flexible graphite	Asbestos Asbestos-PTFE Cotton or rayon Flax, jute or ramie Plastic (pliable) Flexible graphite	Duck and rubber	Asbestos Duck and rubber Flax or cotton Plastic (pliable) Flexible graphite
Hot water	Duck and rubber Leather Plastic (pliable) Flexible graphite	Asbestos Asbestos-PTFE Plastic (pliable) Flexible graphite	Duck and rubber	Asbestos Duck and rubber Plastic (pliable) Flexible graphite

Split-ring seals

Although split-ring seals are most often used for reciprocating motion, they are sometimes applied to hydraulic swivel joints and transmissions. They are compact, relatively inexpensive, and provide long life under harsh operating conditions.

Expanding split-ring seals, or piston rings, are used in compressors, pumps, internal-combustion engines, hydraulic cylinders, and pneumatic cylinders. Contracting split-ring seals, or rod seals, are used in linear actuators where high pressure and temperature, radiation, thermal fatigue, and reliability requirements make packings undesirable. Everything said of piston rings has a counterpart in rod seals.

Both expanding and contracting seals come as one, two, and three-piece seals. Single-ring straight-cut seals are the simplest and most economical, but they also leak the easiest.

Standard step-cut seals are used for unidirectional sealing where leakage is not critical, at bore diameters down to 1⅜ in. Special high-precision step seals are available for applications where leakage is critical. One-piece or two-piece seals with special joint designs are needed for bidirectional sealing. Three-piece seals are used for very small or very large cylinder diameters.

Garter springs and axial springs can be added to any of the seals to ensure contact at sealing surfaces. Contact forces in both axial and radial directions must be large enough to overcome friction. Other things being equal, radial and axial forces should be about the same.

Circumferential seals

These seals are quite similar to rod and piston seals, but are adapted to rotary motion. Circumferential seals are high-speed, low-leakage seals that require less space than face seals. The contacting types undergo high-velocity rubbing at their primary sealing surfaces, and often require cooling.

Hydrostatic and magnetic seals avoid this difficulty. Hydrostatic seals may also suffer from instability in the gas film.

Some circumferentials inhibit leakage in both directions. Primary sealing takes place at the cylindrical surface where high-speed relative motion takes place. A secondary leakage path exists at the housing surface where the seal is seated.

If you think Parker *only* makes O-Rings… Think again!

Fastener Seals • Gask-O-Seals® • Integral Seals® • ThredSeals® • Waveguide Seals • Stat-O-Seals® • Piston Seals • Rod Seals • Wear Bands • Metal V-Seals® • Back-up Rings • U-Packing • V-Packing • Rod Wiper / Scrapers • Custom Molded Shapes • Special Hydraulic & Pneumatic Seals / Packings • Extruded & Cut Components • Silicone and Conductive Cord Stock • Conductive Elastomer EMI / EMC Shielding & Sealing Components • PTFE Piston Rings & Seals • Custom PTFE Components • Drive Belts • Fitting Seals • Head Gaskets • Automotive Seals…

…and, of course, Parker O-Rings!

If Parker produced only a single type of seal, things would be easier for us… but the objective at Parker Seal is to make things easier for *our* customers!

One reason we produce so many types of seals is because the O-ring, effective seal that it is, can't begin to solve all sealing problems in this age of high technology and extreme service conditions.

Another reason is because, while an O-ring *could* be a solution to your particular seal problem… it might not be the *best* solution. We at Parker Seal believe that's what you are entitled to when you specify Parker Products… The very best!

The Parker Seal Group is totally dedicated to providing a complete range of high reliability, top quality sealing and other elastomer products, designed to solve your specific sealing problems in the most economical and practical manner.

One of the major advantages of dealing with Parker Seal is our worldwide network of franchised Parker Seal Distributors. Your local Parker Seal Distributor is fully qualified from both a technical and a business standpoint to assist in solving your sealing problems and to provide high quality sealing solutions on a timely and cost-effective basis.

For your free copy of Parker Brochure PSG4000, "TOTAL SEALING CAPABILITY" or the more specific Parker PPD3700, "TOTAL HYDRAULIC & PNEUMATIC SEALING SYSTEMS", contact any Parker Seal Distributor listed on the following sprea You are also invited to call Parker Seal directly at (714) 851-376 or (800) 272-7537. We'll be happy to send you a copy of one o both brochures.

The next time you have a tough sealing problem, Call on yo local Parker Seal Distributor — he's always ready to provide yo with genuine, high quality, effective, *and* economical Parker sealing solutions.

PARKER SEAL GROUP
18321 JAMBOREE ROAD
IRVINE, CA 92715
(714) 851-3763 or (800) 272-7537
FAX: (714) 851-2127

CALL OR
WRITE FOR
YOUR FREE COPY
TODAY!

Parker Seals…when you can't afford second best!

Circle 269

In 1992, when the heat's on... PARKER DELIVERS!

introducing

PARKER SLC4300

The world's most advanced polyurethane sealing material...

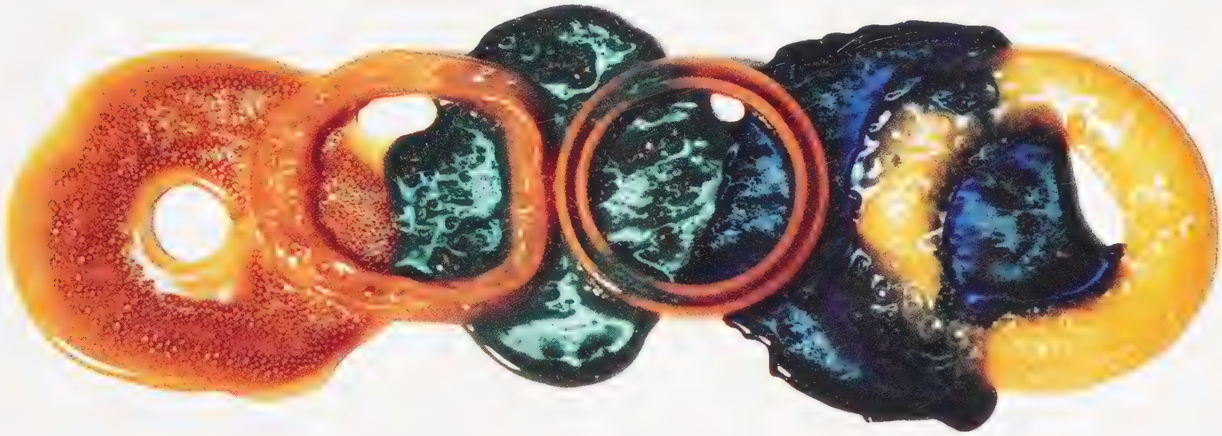


Photo of an actual test sample of six polyurethane seals subjected to +500°F for 15 minutes in hot air. Only the **Parker SLC4300** seal (middle) survived intact. Proof of our claim of superior heat resistance.

s with seal geometry, if Parker Seal only offered a few elected seal materials, life would be easier for us. . . Yet this hilosophy neither serves our customers, nor, in the long run, urselves.

The development of new sealing materials is a major part of he ongoing Parker Seal promise to supply the most reliable igh performance sealing devices in the business.

In that context, Parker Seal is proud to introduce our newest olyurethane sealing material — **SLC4300 High Performance olyurethane.**

ARKER SLC4300 is a Parker developed, high performance olyurethane hydraulic seal material that offers the fluid power ndustry truly unique performance capabilities.

Polyurethane materials have long been known for their esistance to abrasion and wear and for this reason have found xtensive use as hydraulic seals in heavy duty fluid power systems.

Traditional polyurethane materials however suffered several ommon inherent weaknesses: They tended to soften at the pper end of their service temperature range and, as a class, l polyurethane seal material had rather poor long term ompression set properties, resulting in unwanted leakage hen not pre-loaded with a more resilient active element uch as nitrile.

Parker SLC4300 has changed the polyurethane seal performance picture dramatically!

Parker SLC4300 now offers the hydraulic seal user the great strength and abrasion/extrusion resistance of polyurethane in combination with low compression set and high resilience properties comparable to those of nitrile. These attributes are combined with a built-in resistance to softening at high temperature that is unique in the industry. **Parker SLC4300 is capable of operating continuously from −40°F to +275°F while maintaining superior physical properties.**

In fact, we subjected samples of SLC4300 *and* the competition's polyurethane seals to a +500°F hot air environment for 15 minutes. You can see the results in the photograph above. While we do not recommend +500°F as a service temperature, this test illustrates clearly that Parker SLC4300 can and will maintain its unique sealing properties when the "heat's on" in your system.

For samples of Parker SLC4300 and complete test reports on the physical properties of this new seal material, Contact:

PARKER SEAL GROUP
18321 JAMBOREE ROAD
IRVINE, CA 92715
(714) 851-3763 or (800) 272-7537
FAX: (714) 851-2127

Parker
Seals

Circle 268

AUTHORIZED PARKER SEAL DISTRIBUTORS

ALABAMA

Alabama Seal and Packing
1705 29th Court South
Birmingham, AL 35209
205/879-7225
FAX : 205/871-4442

ARIZONA

State Seal Co.
4135 East Wood Street
Phoenix, AZ 85040
602/437-1532
FAX: 602/437-4332

CALIFORNIA

AAR Hardware
16800 Edwards Road
Cerritos, CA 90701
310/926-2777
FAX: 310/802-6900 or 6901

Ad-Tech Seal, Inc.
14640-C Industry Circle
La Mirada, CA 90638
213/921-6608
FAX: 714/523-9650

Bay Seal Co.
1550 W. Winton Avenue
Hayward, CA 94540
415/732-7000
FAX: 415/782-2651

Burbank Aircraft Supply
10671 Lanark Street
Sun Valley, CA 91352-0369
818/875-2353
FAX: 818/768-9829

Cal-State Seal &
Fluid Components, Inc.
13891 Nautilus Drive
Garden Grove, CA 92643
714/554-9080
619/434-0205
FAX: 714/554-9761

Cal-State Seal San Diego
3360 Sports Arena Blvd.
Suite "A"
San Diego, CA 92110
619/224-2007
FAX: 619/224-2036

Eriks West
Division of North west Seal
1166 Knollwood Circle
Anaheim, CA 92801
714/826-2000
800/437-3257
FAX: 800/255-1461

Mayo Hydraulics, Inc
3946 East Brundage Lane
Bakersfield, CA 93307
805/324-2260
FAX: 805/324-9124

Nor-Cal Seal Co.
840 Doolittle Drive
San Leandro, CA 94577
415/569-7371
FAX: 415/569-4416

Valley Seal Co.
6430 Variel Avenue, Suite 106
Woodland Hills, CA 91367
213/873-3630
818/883-3505
FAX: 818/883-0106

COLORADO

Aspen Seal & Packing
1880 W. Hamilton Place
Englewood, CO 80110
303/761-9049
FAX: 303/761-5345

CONNECTICUT

Valtec, Inc.
P.O. Box 747
Ivorytown, CT 06442
203/767-8211
FAX: 203/767-2918

FLORIDA

Florida Seal & Rubber
10106 Cedar Run
Tampa, FL 33619
813/681-5502
FAX: 813/654-2525

R. E. Hoose. Inc.
Division of Eriks Corp.
3845 N. W. 25th Street
Miami, Fl 33142
305/871-4055
800/233-7457
FAX: 305/871-1285

Hydraulic House, Inc.
1342 W. Church Street
Orlando, FL 32805
407/422-2317

GEORGIA

Go-Air, Inc.
3562 Elm Street
Hapeville, GA 30354
404/768-1121
FAX: 404/768-9208

United Seal and Rubber
7025-C Ameviler Industrial Drive
Atlanta, GA 30360
404/729-8880
FAX: 404/729-8992

HAWAII

Hawaiian Fluid Power Corp.
803 Ahua Street
Honolulu, HI 96819
808/833-4516
FAX: 808/839-6471

ILLINOIS

Catching Fluidpower, Inc.
P.O. Box 6066
Broadview, IL 60153-0766
708/344-7272
FAX: 708/344-7357

Gasket & Seal Fabricators
1640 Sauget Industrial Parkway
Sauget, IL 62206
314/241-3673
FAX: 618/332-0450

Interstate Packing & Seals
Box 120, Route 1
Litchfield, IL 62056
217/324-3133
FAX: 217/324-2350

Lucas Fluid Power, Inc.
Seals & Engineering Division
5012 28th Avenue
Rockford, IL 61109
815/398-5400
FAX: 815/399-3183

Spence Tool & Rubber Co.
704 South Adams Street
Peoria, IL 61602
309/674-4191
FAX: 309/676-1889

Tech-Syn
225 Mt. Prospect Ave.
Mt. Prospect, IL 60056
312/774-1600
708/392-2210
FAX: 708/398-2525

INDIANA

Brake Supply Co., Inc.
P.O. Box 447
Evansville, IN 47703
812/479-6881
FAX: 812/479-6890

Power Components Division,
Seal Products, Inc.
520 E. Washington Blvd.
Fort Wayne, IN 46802
219/426-2700
FAX: 219/423-3600

Seal Products, Inc.
3312 English Avenue
Indianapolis, IN 46201
317/633-7277
FAX: 317/633-7275

IOWA

All Tech
Railroad & Main Streets
P.O. Box 458
Elkhart, IA 50073
515/367-5915
FAX: 515/367-3865

E.S.P. Engineered Sales
5920 Dry Creek Lane N.E.
Cedar Rapids, IA 52410-0015
319/393-4310
FAX: 319/393-5327

E.S.P. Engineered Sales
817 E. 59th Street
P.O. Box 2783
Davenport, IA 52807
319/388-9343
FAX: 319/388-0057

KANSAS

Wm. F. Hurst Co.
2121 Southwest Blvd.
Wichita, KS 67277
316/942-7474
FAX: 316/942-1539

Swan Engineering & Supply Co.
550 Shawnee Avenue
Kansas City, KS 66105
913/371-7425
FAX: 913/371-4210

KENTUCKY

General Rubber & Plastics
3118 Preston Highway
Louisville, KY 40213
502/635-2605

I.B. Moore Company, Inc.
648 Laco Drive
Lexington, KY 40510
606/255-5501
FAX: 606/254-4389

Pneu-Draulics, Inc.
111 Brookside Drive
Nicholasville, KY 40356
606/885-4155
FAX: 606/887-4165

LOUISIANA

Advanced Seals & Packing
658 Lesson Court. Unit 1
Harvey, LA 70058
504/367-7325
FAX: 504/362-7215

MAINE

Webster Engineering
Industrial Park
14 Enterprise Street
P.O. Box 1904
Lewiston ME 04240
207/783-9108
FAX: 207/782-8634

MASSACHUSETTS

The Hope Co.
70 Bearfoot Road
Northboro, MA 01532
508/393-7660
FAX: 508/393-8203

MICHIGAN

Depatie Fluid Power Co.
301 Peekstok Road
P.O. Box 2499
Kalamazoo, MI 49003
616/381-4590
FAX: 616/381-1391

Flood Supply
623 Industrial Park Drive
Iron Mountain, MI 49801
906/779-1500
FAX: 906/779-1288

Roger Zatkoff Co., Inc.
P.O. Box 413
Farmington Hills, MI 48024
313/478-2400
FAX: 313/478-3392

Roger Zatkoff Co., Inc.
P.O. Box 88023
Grand Rapids, MI 49508
616/698-6880
FAX: 616/698-6877

Roger Zatkoff Co., Inc.
1707 Sheridan
Saginaw, MI 48601
517/754-2900
FAX: 517/754-2974

MINNESOTA

Applied Power Products
1240 Trapp Road
Eagan, MN 55121
612/452-2250
FAX: 612/452-9476

E.S.P. Engineered Sales
12805 Industrial Park Blvd.
Plymouth, MN 55441-3910
612/550-9425
FAX: 612/550-9427

R.E. Purvis & Associates
7740 West 78th St.
Bloomington, MN 55439
612/829-5532
FAX: 612/829-5838

SIM Supply, Inc.
1226 E. 16th Ave., Box 382
Hibbing, MN 55746
218/262-6125
FAX: 218/262-6474

MISSOURI

House of Tools & Eng.
436 Anglum Road
Hazelwood, MO 63042
314/731-4444
FAX: 314/731-4424

NEBRASKA

Baum Iron Company
1221 Harney Street
Omaha, NE 68102
402/345-4122
800/228-9222
FAX: 402/345-0663

Swan Eng. & Supply Co.
10155 "J" Street
P.O. Box 27091
Omaha, NE 68127
402/339-1442
FAX: 402/339-1432

NEW JERSEY

Sandem Industries
10 Park Place
Butler, NJ 07405
201/492-1900
FAX: 201/492-1213

Service Seal Division
of U.S. Brass & Copper Corp.
639 East Elizabeth Avenue
Linden, NJ 07036
908/486-6171
FAX: 908/486-6176

NEW MEXICO

Southwest Seal & Supply Co.
1413 1st Street NW
Albuquerque, NM 87102-1533
505/247-0265
800/421-3737
FAX: 505/242-5419

NEW YORK

AAR Hardware
200 Saw Mill River Road
Hawthorne, NY 10532
914/747-0500

Durham Aircraft
156 Duffy Avenue
Hicksville, NY 11801
516/681-9800
FAX: 516/935-9361

Hydro-Pneumatics, Inc.
85 Brook Avenue
Deer Park, L.I., NY 11729
516/242-2900
FAX: 516/242-0836

Sealing Devices, Inc.
4400 Walden Avenue
Lancaster, NY 14086
716/684-7600
FAX: 716/684-0644

NEW YORK (Continued)

Staver Hydraulics Co., Inc.
P.O. Box 41
Waverly, NY 14892
717/888-5829
FAX: 717/888-5832

Web Seal, Inc.
15 Oregon Street
Rochester, NY 14605
716/546-1320
FAX: 716/546-5746

Web Seal, Inc.
206 Marcellus Street
Syracuse, NY 13204
315/475-8496
FAX: 716/546-5746

Al Xander Co., Inc.
266 Turk Hill Park
Fairport, NY 14450
716/223-8025

Al Xander Co., Inc.
2231 Wehrle Drive
Buffalo, NY 14221
716/632-6896
FAX: 716/632-6921

NORTH CAROLINA

Smith Seal of NC
8441 Garvey Drive
Raleigh, NC 27604
919/790-1000
FAX: 919/878-8377

Southern Rubber Co., Inc.
2209 Patterson Street
Greensboro, NC 27407
919/299-2456
FAX: 919/294-4970

OHIO

Bearings, Inc.
3600 Euclid Avenue
Cleveland, OH 44115
216/881-2838
FAX: 216/881-8988

cbb Seal Co.
3865 Carnegie Avenue
Cleveland, OH 44115
216/391-3300
FAX: 216/391-0003

Durox Company
12351 Prospect Road
Strongsville, OH 44136
216/238-5350

J.N. Fauver Co., Inc.
11253 Williamson Road
Cincinnati, OH 45241
513/247-9900
FAX: 513/247-9913

Hersh Packing & Rubber
312 North High Street
Canal Winchester, OH 43110
614/837-5526
FAX: 614/837-6219

Mega Fluidline Products
425 Kennedy Road
Akron, OH 44305
216/733-7921
FAX: 216/733-2023

Southern Ohio Seal Co.
3025 Princeton Glendale Road
Hamilton, OH 45011
513/874-0067
FAX: 513/874-8537

Roger Zatkoff Co.
8929 Airport Highway
Holland, OH 43528
419/866-1600
FAX: 419/866-4668

OKLAHOMA

Seal Co. Enterprises
2810 N.W. 10th Street
Oklahoma City, OK 73107
405/947-3307
FAX: 405/949-9003

Seal Co. Enterprises
1235 North Sheridan Road
Tulsa, OK 74115
918/836-0441
FAX: 918/836-5169

OREGON

Air-Oil Products
865 Conger Street
Eugene, OR 97401
503/485-2022
FAX: 503/485-8857

Air-Oil Products
2400 East Burnside Street
Portland, OR 97214
503/234-0866
FAX: 503/232-2615

Fluid Connector Products
3342 N.W. 26th Avenue
Portland, OR 97210
503/228-0190
FAX: 503/228-5331

PENNSYLVANIA

Allegheny York Co.
Box 3327
York, PA 17402-0327
717/266-6617
FAX: 717/266-6371

Allied Seals, Inc.
137 Donald Lane
Johnstown Industrial Park
Johnstown, PA 15904
814/269-3664
FAX: 814/269-3341

D.B.R. Industries
18 Penns Trail
Newton Industrial Commons
Newton, PA 18940
215/968-6100
FAX: 215/860-1043

Dees Corporation
1151 Matsons Ford Road
W. Conshohocken, PA 19428
215/828-5500
FAX: 215/834-8275

Industrial Rubber Products
294 Corliss Street
Pittsburgh, PA 15220
412/771-7800
FAX: 412/771-2700

Sealing Devices, Inc.
2660 West 14th Street
Erie, PA 16505
814/833-9977
FAX: 814/833-4526

Sealing Specialists & Service
969 Wm. Flynn Hwy., Route 8
Glenshaw, PA 15116
412/487-8282
FAX: 412/487-2826

Staver Hydraulics Co., Inc.
7709 Beth-Bath Pike
Allentown, PA 18014
215/837-1818
FAX: 215/837-9585

Staver Hydraulics Co., Inc.
35 East Uwchlan Ave. #320
Exton, PA 19341
215/594-0540
FAX: 215/594-0545

Al Xander Co., Inc.
36 E. South Street
Corry, PA 16407
814/665-8268
FAX: 814/664-7343

RHODE ISLAND

Niantic Rubber Co.
144 Kenwood Street
Cranston, RI 02907
401/942-0900
FAX: 401/943-4754

SOUTH CAROLINA

Wyatt Seal, Inc.
324 Piney Wood Road
Columbia, SC 29212
803/772-0810
FAX: 803/731-1788

TENNESSEE

Mid 10 Seal & Packing
4721 Trousdale Drive, Suite 120
Nashville, TN 37204
615/331-6876
FAX: 615/834-5677

Nashville Rubber & Gasket
1900 Elm Tree Drive
Nashville, TN 37211
615/883-0030
FAX: 615/885-9507

TEXAS

A-1 Gasket & Ind. Supply
2018 West 2nd Street
Odessa, TX 79763
915/332-1772
FAX: 915/334-7810

A & I Supply Co.
139 North Cotton Street
El Paso, TX 79901
915/533-8224
FAX: 915/533-3824

Alamo Aircraft Supply, Inc.
2538 SW 36th Street
San Antonio, TX 78237
512/434-5577

Gulf Coast Seal, Inc.
6218 Long Drive
Houston, TX 77087
713/643-9510
FAX: 713/643-7941

Parker Seal Distribution Center
6260 Brookhill Drive
Houston, TX 77087
713/649-7592
FAX: 713/649-4132

Santech Industries
2450 Handley Ederville Road
Fort Worth, TX 76118-6946
817/589-1212
FAX: 817/595-1575

Texas Seal of Houston
4540 S. Pinemont, Suite 122
Houston, TX 77041
713/462-8871
FAX: 713/462-3309

Texas Seal Supply Co.
606 N. Great S.W. Parkway
Arlington, TX 76011
817/640-1193
FAX: 817/640-1930

UTAH

Hydra-Pak, Inc.
1605 West 2100 South
Salt Lake City, UT 84126-0776
801/973-7325
FAX: 801/565-1008

Wencor West, Inc.
1675 N. Mountain Springs Pkwy.
Springville, UT 84663-0514
801/489-3615
FAX: 801/489-9777

VIRGINIA

American Bearing & Power
Transmission, Inc.
1406 Leslie Avenue
Alexandria, VA 22301
703/548-4935

Dominion Seal & Packing Co.
5905 Tangle Ridge Drive
Mechanicsville, VA 23111
804/746-9813
FAX: 804/798-9063

Hampton Rubber Company
1669 W. Pembroke Avenue
Hampton, VA 23661
804/722-9818
FAX: 804/722-9162

WEST VIRGINIA

National Mine Service Co.
696 Fairmont Road
Morgantown, WV 26505
304/296-2517
FAX: 304/292-5864

WASHINGTON

Air-Oil Products Corp.
6353 Sixth Avenue South
Seattle, WA 98108-3437
206/767-7750
FAX: 206/762-4736

Northwest Seals, Inc.
14600 Interurban Avenue, South
Seattle, WA 98168
206/243-9660
FAX: 206/243-4718

WISCONSIN

Great Lakes Rubber & Supply
P.O. Box 09128
Milwaukee, WI 53209-0128
414/352-8800
FAX: 414/352-8854

G.A. Miller Co.
Box 205
Prentice, WI 54556
715/428-2500
FAX: 715/428-2574

CANADA

Coast Seal Co., Ltd.
1-11711 No. 5 Road
Richmond, BC V7A 4E8
604/272-5141
FAX: 604/272-0737

D & D Packing & Seals
1225 Aerowood Drive
Mississauga, Ontario L4W 1B9
416/625-2033
FAX: 416/625-4934

HyPower Systems, Inc.
3223 Millar Avenue
P.O. Box 2021
Saskatoon, Sask. S7K 3S7
306/242-3111
FAX: 306/242-0860

Kepco Sealing Supplies, Inc.
1121 Sanford Street
Winnepeg, Manitoba R3E 3A1
204/783-9617
FAX: 204/783-6091

Les Joints Entanches R.B. Inc.
8585 Henri Bourassa Quest
Ville St. Laurent, Quebec
H4S 1P7
514/334-2220
FAX: 514/333-8329

Les Joints & Garnitures D&D Inc.
5670 Boulevard Thimens
Ville St. Laurent, P.Q. H4R 2K9
514/745-4044
FAX: 514/745-3281

PAC Seal
3265 Parsons Road (99th St.)
Edmonton, Alberta T6N 1B4
403/463-5115
FAX: 403/450-1395

Seals Unlimited, Inc.
58 Oakwood Avenue, North
Port Credit, Ontario L5G 3L8
416/278-1326
FAX: 416/278-2548

Sealtech Supply, Inc.
1070 Kamato Road, Unit 7 & 8
Mississauga, Ontario L4W 2W5
416/238-5885
FAX: 416/238-1664

Wesco Aircraft Canada, Ltd.
6175 Kestrel Road
Mississauga, Ontario L5T 1Z2
416/670-2624

Wriason Seals Ltd.
1824 Pandora Street
Vancouver, BC V5L 1M5
604/251-3554
FAX: 604/251-6162

PARKER SEAL CANADIAN TRADING SUBSIDIARY
5935 Ambler Drive
Mississauga, Ontario L4W 2K2
416/625-8661
FAX: 416/625-8258

Parker
Seals

Contacting circumferential seals are highly effective for sealing gases, but less effective with liquids, although they are used in some liquid applications. Hydrostatic seals can only be used with gases, while magnetic seals can be used with both liquids and gases.

Compression packings

Packings are seals that normally are packed around a shaft or rod and compressed to provide a sealing effect. A packing normally consists of many sections (or one long continuous strand wrapped several times to achieve a section effect); when compressed longitudinally, they expand radially to seal.

Normally, packings are not designed to produce a leak-free seal. Instead, they are tightened enough to produce a minimum but positive leakage. In many applications, the leakage is intended to lubricate the packing material; some manufacturers advise the packings be lubricated if this leakage falls below specified minimums or if it is of a nonlubricating liquid. The modest leakage reduces friction and wear.

Packing material may be supplied in many shapes, including impregnated yarn, continuous strands, or continuous strands of a compressed square-section material. Also, various types of interlocking packing shapes are provided; many of these shapes are proprietary developments of specific companies in the packing field. One very common style is the familiar V-packing, in which the seal-ring mating surfaces are designed to permit a void between each ring which acts as a lubrication reservoir.

Many materials are used in packings,

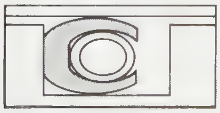
Characteristics of compression-packing materials

Fiber	Maximum temperature (°F)	Fluid resistance (pH)	Shaft speed (fpm)	Relative cost
Asbestos	1,200	2-12[a]	2,200-2,400	1
Teflon	500	0-14	1,200	4-5
Graphite	1,200	0-14[b]	4,000	20
Carbon	1,200	0-14[b]	3,000	12-13
Aramid	500	3-11[a]	2,400	3
Glass	500	2-12[a]	2,000	2
Teflon-graphite	500	0-14[b]	2,200	6
Glass-polyamide	500	2-12[a]	1,900	3

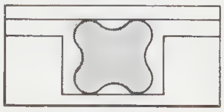
[a] With TFE impregnation. [b] Except strong oxidizers in the 0 to 2 pH range.

TYPES OF PACKING

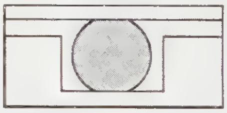
Hollow rings can be used in any O-ring or squeeze-packing application, and fit standard O-ring glands. However glands should be split. Covers are usually made of PTFE.



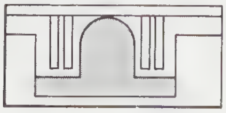
Lobed rings, or X-rings, can be used in conventional O-ring grooves for reciprocating, oscillating, and rotary motions. Lobed rings need only low squeeze — down to 1% in some applications — and can handle rotary speeds up to about 900 fpm. Lobed rings have less side-to-side motion than O-rings, and less breakaway friction.



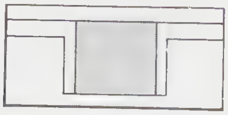
O-rings are the most common form of squeeze packings. They are inexpensive, seal in both directions, and are used for reciprocating, oscillating, and slow rotating motions. Except for floating-ring applications, they require about 10% squeeze. Typically, O-rings seal pressures up to 1,500 psi. Higher pressures can be sealed if backup rings are used.



T-rings are used as rod or piston seals for reciprocating motion, and can be used for oscillation at low sealing pressures. Like D-rings, they do not suffer from spiral failures, but do require backup rings. T-rings can be used for sealing pressures up to 20,000 psi.

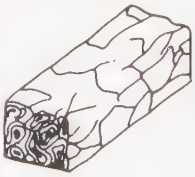


Square rings are for static applications in which fluid pressures do not exceed 1,500 psi. They should never be used for rotary or oscillatory motion, and are rarely used for reciprocation.

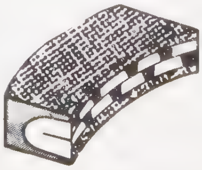


METALLIC PACKINGS

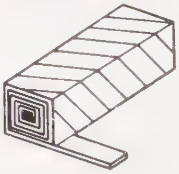
Folded and twisted packings are made of continuous thin ribbons of foil loosely spiral wrapped and then folded, twisted, and squared to the proper size. Each layer of foil is lubricated, so voids form lubrication reservoirs. Common materials are lead, copper, aluminum, phosphor bronze, and nickel.



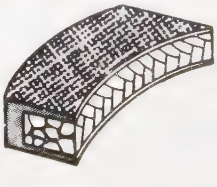
Braided core packings have a core of asbestos, flax or plastic wrapped with lead, copper, or aluminum foil or with braided metal wire, Flax is always braided.



Spiral-wrapped packings are made with thin ribbons of metallic foil in layer-over-layer construction. Ends are squared, and each layer is usually lubricated with oil or graphite, Common materials are lead, copper, and aluminum. These packings are flexible and durable, but not resilient.



Metal core packings have an outer casing of fabric and an inner core of metal and rubber, spiral-wrapped lead, or braided copper. The metallic cores are exposed on only one face.



ranging from solid metal to flax or cotton. The more common varieties include aluminum, copper, and lead foil, aluminum and copper braided wire, PTFE elastomers (tapes and solid sections), leather, flax, cotton, flexible graphite, plastics, and formerly asbestos. Materials are selected on the basis of service temperature of the application and the process fluid to be used. Packing manufacturers provide detailed information on compatibility and on temperature capabilities of the different packing materials.

An old rule of thumb states that optimum packing length is 1.5 times stem diameter, but like most rules of thumb, it has only limited validity. A better equation for packing length is

$$\frac{S}{d_i}=\frac{1}{4K}\left[\frac{(d_o/d_i)-1}{\mu_1+\mu_2(d_o/d_i)}\right]\ln\frac{KP_o}{P_r}$$

where S = packing length, in.; d_i = stem diameter, in.; K = packing stress ratio; d_o = bore diameter, in.; μ_1 = dynamic friction coefficient between stem and packing; μ_2 = static friction coefficient between bonnet and packing; P_o = pressure at packing follower, psi; and P_r = radial packing pressure, psi.

Properties and uses of gasket materials

Classification	Special characteristics	General uses
Rubber-asbestos	Tough and durable. Dimensionally stable. Relatively incompressible. Good steam and hot water resistance. Oil and solvent resistance determined by charateristics of rubber binder.	Heavy-duty bolted and threaded joints, as in water and steam pipe fittings, manifold connections. Temperatures to 500°F.
Cork-and-rubber	Provides fluid barrier and resilience with compressibility. Properties of flow versus compression subject to controlled variation. Lower tensile and elongation properties than rubber. Chemical properties about same as base polymers. Higher in cost than cork composition or fiber types, but lower than straight rubbers. Does not extrude from joint. Die cuts well. High coefficient of friction.	General-purpose gasketing, except steam lines, combustion chambers, etc. Enables design of metal-to-metal joints with gasket positioned in channel or counterbore, with no allowance for flow. High friction keeps gasket positioned even where closing pressure is not perpendicular to flange faces.
Cork composition	General-purpose material. Variable as to binder, texture, and hardness (density). Compressible. High friction whether dry, wet, or oily. Low cost. Excellent oil and solvent resistance. Poor resistance to alkalies and corrosive acids.	Mating rough or irregular parts, as glass, light stampings, unfinished castings. Oil sealing at low cost in normal range of temperatures and pressures.
Rubber, plastics	Highly adjustable according to compounding, hardness, modulus, fabric reinforcement, etc. Generally impervious. Not compressible.	Installations involving stretching over projections, or where flow of gasket into threads or recesses is desired. For lowest compression set and maximum resistance to fluids such as alkalies, hot water, and certain acids. Ability to be molded permits use for special design and assembly conditions.
Plastic foams	Good thermal insulators, usually self-extinguishing or with low burn rates. Variable chemical reactivity, depending on plastic resin.	Light, vapor, and dust barriers in low-pressure applications.
Elastomeric sponge	Compression set varies with type and compound. Good variety of temperature ranges.	Low-pressure applications.
Paper:		
Untreated	Low in cost; noncorrosive.	Spacers, dust barriers, splash seals, where breathing and wicking not objectionable.
Treated	General-purpose material having better tensile strength than cork composition, but less compressibility. Good oil, gasoline, and water resistance, but alternate wet and dry cycles may cause shrinkage and hardening of some types.	Machined or reasonably uniform flanges where adequate bolt pressures can be applied. Relative firmness and high tensile strength permit use of thin gaskets to give good alignment of covers and connected parts.
Combination constructions	Innumerable modifications available, depending on materials used and methods of combining.	Usually employed for extreme conditions and special purposes.

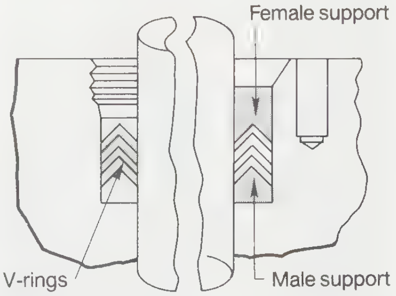
Metallic gaskets

Metallic gaskets are used for pressure and temperature extremes that cannot be handled by nonmetallic gaskets. If the product of operating pressure in psi times operating temperature in °F exceeds 250,000, metallic gaskets should be used. Metallic gaskets are also used for temperatures below −65°F, above 850°F, and for pressures above 1,200 psi. Other conditions calling for metallic gaskets include vacuum below 10^{-4} torr and radiation above 10^8 rad.

Nonmetallic gaskets

A gasket provides a barrier against fluid transfer across mating static surfaces. Proper selection depends on how

V-RING PACKINGS



V-rings are installed in sets, each set consisting of a number of rings, a male adapter, and a female adapter. The number of rings in a set depends on pressure and the ring material.

Whenever possible, solid V-rings should be used, rather than split rings, because they provide better sealing and longer life. If split rings must be used for ease of installation, the joints should be staggered on successive rings.

The function of the male and female adapters is to support the rings. The female adapter is the more critical, and should have the same included angle as the rings (usually 90°). The male adapter should have the same angle as the female.

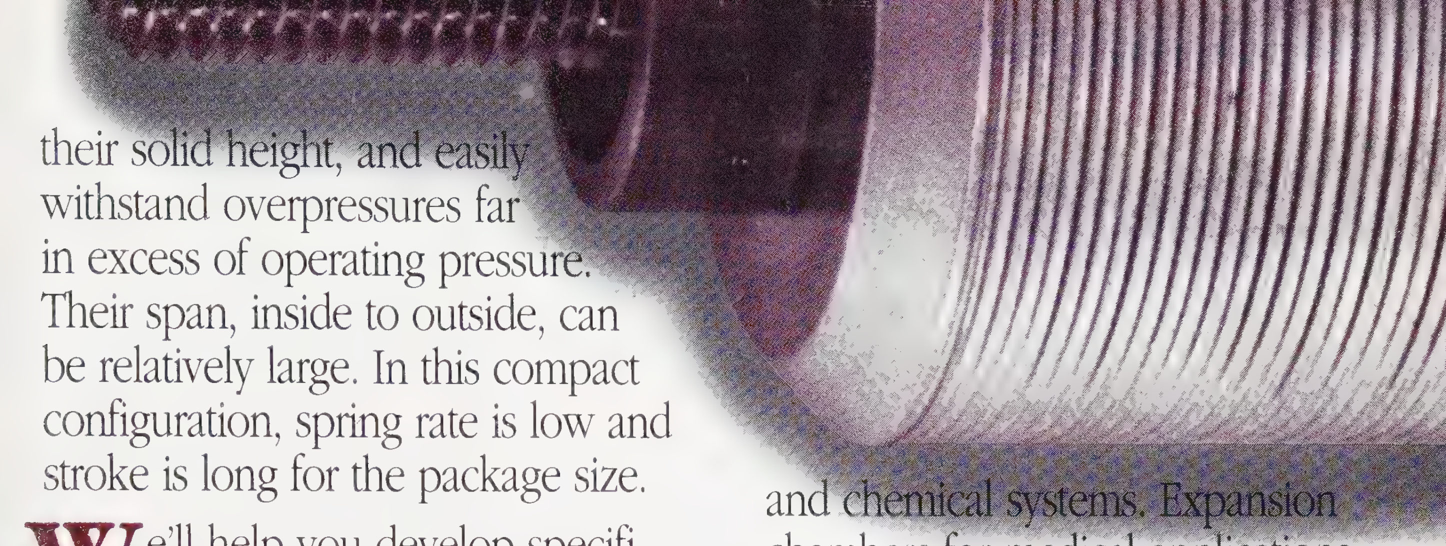
V-rings are usually packed in glands, although they can be installed on pistons.

Bellows: From Beginning

If you need design information on bellows, ask the company that invented them. For over 80 years, Robertshaw has conducted continuous research on new bellows designs and applications, stretching the limits of size and materials. Here, you have access to a vast amount of engineering data, experience and technical know-how in both formed and welded bellows types.

Single-ply formed bellows are rolled or hydraulically corrugated from a seamless metal tube in large quantities. Multi-ply formed bellows can be designed for high pressure applications without excessive loss of flexibility. This fabrication method produces quality bellows at the lowest cost per unit.

Welded bellows are manufactured by individually welding together alternate inside and outside edges of washer-shaped diaphragms. These bellows can collapse to

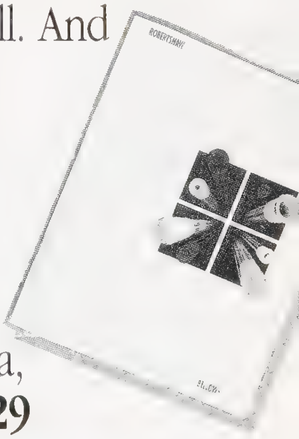


their solid height, and easily withstand overpressures far in excess of operating pressure. Their span, inside to outside, can be relatively large. In this compact configuration, spring rate is low and stroke is long for the package size.

We'll help you develop specifications for the best bellows to do your job. But Robertshaw gives you more than good engineering advice. Instrument-quality production is routine. Testing facilities are unequalled in the industry. We've built high pressure assemblies for space vehicle propulsion engines and guidance systems. Valve stem seals for high vacuum, cryogenic and chemical systems. Expansion chambers for medical applications. Electronics controls. You name it.

If you don't like loose ends, we can build your entire bellows assembly from end to end. Ready for you to install. And we take single-source responsibility for it all.

For a catalog of bellows applications, materials, types, characteristics and data, phone: **(800) 228-7429**



Robertshaw
TENNESSEE
A SIEBE COMPANY

Your single-source supplier.

To End.

P.O. Box 400 / Knoxville, TN 37901-0400 / (615) 546-0550 / FAX (615) 544-5193

Circle 270

well the gasket material meets four basic requirements.

Although many material combinations are suitable for gaskets, the most common are cork compositions, cork and rubber, plant and vegetable fibers, rubber, plastics, and paper. Flexible plastic foams and elastomeric sponge are coming into use, as is flexible graphite. Formerly, asbestos was widely used.

These materials are often laminated with each other to combine the properties of a strong, but relatively incompressible material with those of a highly compressible but weak material. For example, cork composition and vegetable fiber are often laminated together; depending on end use, either may serve as the center filler.

Treatments and coatings

For many applications, gaskets are treated with various other metals to achieve better surface properties, encourage or discourage adhesion, or to resist chemical or microbial attack.

Adhesives are used where an immediate permanent bond is needed. They are usually a synthetic rubber, a resin, or a combination.

Fungicides resist mold growth, and may be an integral part of the gasket material or applied as surface treatment. Common fungicides are beta-naphthol, pentachlorophenhol, salicylanilide and various compounds of copper and mercury.

Graphite is applied as a dry flake, mixed with oil, or in a water emulsion to level surfaces and to inhibit adhesion.

Oil and hot paraffin dip coats prevent loss of moisture during storage.

Reflectors such as aluminum paint or lacquer offer some protection to gaskets located near heat sources.

Rubber coatings such as neoprene are applied as a dip coat to reduce oil penetrations, loss of moisture, and installation breakage. Polysulfide coatings help level the surfaces and promote sealing contact of relatively hard-fiber sheet materials.

Talc and mica dust are applied dry or in an adhesive vehicle to cut surface friction of gaskets. They are often used where mating parts must be rotated to close the joint.

Diaphragms

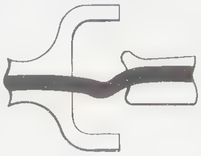
Diaphragms are seals that span the gap between reciprocating and stationary members. Flat and convoluted diaphragms are used where there is relatively little motion involved, and rolling diaphragms are used for longer motions.

Sealants

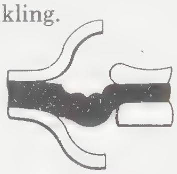
Sealants are categorized as hardening and nonhardening. Whether a sealant is hardening or nonhardening

DESIGN TIPS FOR FLAT DIAPHRAGMS

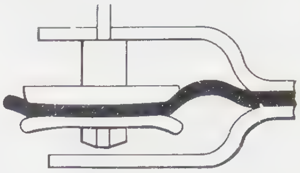
Avoid sharp corners. Make radius at least twice thickness, preferably more.



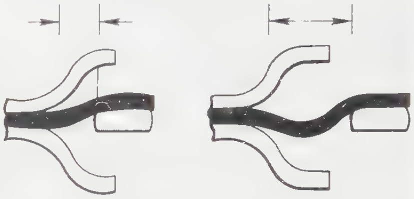
Keep diaphragm thin enough to prevent wrinkling.



Incorporate mechanical stops limiting diaphragm movement to 90% of maximum possible stroke.



Keep free space wide enough for flexing, yet as narrow as possible for the stroke requirement. Wide space increases stress in material.



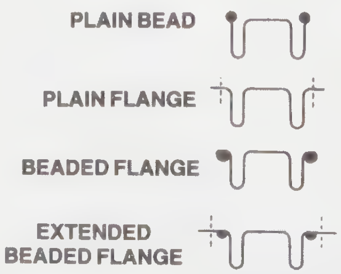
BASIC DIAPHRAGMS

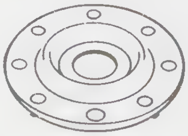
"Flat" diaphragms are not necessarily flat, many are made with convolutions. Even when a diaphragm is made flat, convolutions are formed by fluid pressure during the working cycle. Also diaphragms made flat are distorted out of a single plane when there is relative movement of the diaphragm assembly. This distortion requires an elongation of the fabric cord.

Although diaphragms are generally made of flexible, stretchable material, designs should avoid elongation of diaphragm during its working stroke. This limitation is sometimes avoided by use of one or more convolutions. These allow the diaphragm to flex rather than stretch. Most diaphragms can withstand flexing indefinitely, but stretching can cause fatigue failures. Rolling diaphragms have a full 180° convolution, and are used as long-travel bellows or radially sealed hydraulic pistons with zero leakage. Some are made initially in the shape of a top hat, and the convolution is made by hand during assembly. Others are made with a molded-in convolution, which tends to restrict stroke length.

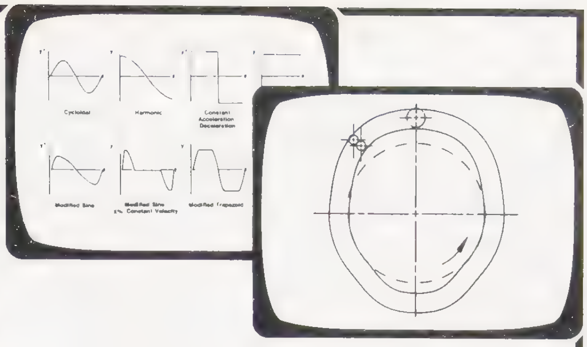
As a rule, rolling diaphragms should not be used in applications where they are subjected to pressure reversals, because reversals may force the diaphragm out of rolling convolution and shorten its life. However, special diaphragms that accept pressure reversals without sidewall distortion are available.

Design features that increase diaphragm life include tapered pistons and curved-lip retainers. Tapered pistons reduce circumferential compression of the sidewall, and curved-lip retainers keep diaphragms from reverting to their as-molded shape. Diaphragms with molded-in convolutions do not need curved-lip retainers.





CAM PC SOFTWARE SIMPLIFIES COMPLEX DESIGNS


Cycloidal
Harmonic
Constant Acceleration Deceleration
Modified Sine
Modified Sine Constant Velocity
Modified Trapezoid

This easy-to-use software takes you from concept to working cam in three simple steps you'll complete in a few minutes ...

STEP 1 — Describe the motion requirements of the cam follower by selecting individual kinematic profiles from the comprehensive program library.

STEP 2 — Synthesize system kinematics by linking together the profile segments. Individual profile segments are easily added, changed, or deleted as necessary.

STEP 3 — Compute the cam geometry as well as the physical properties of the cam and follower. Calculations include contact stress, pressure angle, and radius of curvature. Cam forces and inertial loads can be modeled.

Program Specifications:
Program designs plate, conjugate, barrel or linear cams * Select from 13 kinematic design profiles * Translating or oscillating followers * Computed output includes follower displacement, velocity, acceleration and jerk, pressure angle, radius of curvature, contact stress, required forces and torques . . . and much more.

ALSO AVAILABLE! CAM Designer Post Processor . . .
Computes cutter and/or grinder coordinates so you can precision cut your cam designs on a CNC machine.

CAM Designer, disks and 170-page user manual. The system manual serves as a valuable reference book for optimum cam design	$1195
CAM Designer Post Processor	$ 995
CAM Designer with Post Processor (save $195).	$1995
Completely functional demonstration package	$50

System Requirements: IBM PC line of computers and 100% compatibles, 640k RAM with math coprocessor, Color or enhanced graphics, Digital plotter (recommended)

SATISFACTION GUARANTEED! Use this powerful new software program on your PC. If you're not satisfied, just return the program within 30 days for full credit or refund.

Order now toll-free 800-321-7003 (in Ohio 216/696-7000)

Penton Education Division • 1100 Superior Avenue • Cleveland, Ohio 44114

depends upon its chemical composition and curing characteristics, rather than on its initial form. Sealants generally come in nonsolid forms in a wide range of viscosities. Some epoxy sealers come in powdered form and must be melted to be applied. Certain asphalt-based sealers and waxes are solid and are applied by a hot-melt system. Thermosetting film adhesives used for sealing also come in tape form and require heat and pressure for curing.

Hardening sealants may be rigid or flexible, depending on their composition. Nonhardening types are characterized by plasticizers that come to the surface continually, so that the sealant stays "wet" after application. Nonhardening sealants are characterized by the "mastics" that are applied to seams with a trowel or brush. They cannot be depended on for joining, although some formulations are used as adhesives in very low-stress joints.

Tapes are available in a variety of backings and with pressure-sensitive or solvent-activated adhesives. Some nonhardening sealants are so viscous that they can be packaged in "tape" form. For purposes of this chapter, they are not considered to be sealing tapes, but simply another form of a heavy-consistency nonhardening sealant.

Selection factors

Many factors enter into the selection of a sealant, not the least of which are

SORTING OUT SEAL MATERIALS

The ideal seal material combines the following properties: good memory, toughness and abrasion resistance, chemical resistance, wide temperature range, and low cost. Unfortunately, no one seal material provides the best combination of all these properties, and some trade-offs are necessary to choose the best material for an application.

The base elastomer is the most important part of a seal material, controlling the basic characteristics of the finished seal. Following is a description of available materials and their properties.

Neoprene was one of the first, and is still the best known, synthetic rubber. Its resistance to petroleum fluids is much better than that of natural rubber. However, neoprene has limited resistance to many fluids. Therefore, it is sometimes a compromise choice to seal a mixture of fluids for which no single elastomer is suitable.

Nitrile (or Buna-N) is the workhorse of the sealing industry. More nitrile rubber is used for seals than all other elastomers combined. This is because of its excellent resistance to petroleum and is useful working temperature range of −40 to 225°F for most compounds. Special nitrile compounds extend this temperature range, but at some sacrifice to other properties.

Butyl has a low permeability rate, which means that gases escape at a slower rate through butyl than through almost any other elastomer. This low permeability and a good temperature range (−65 to 225°F) make butyl the preferred rubber for sealing gases.

Ethylene propylene rubber has superior resistance to hot water and steam, and good resistance to ultraviolet light, oxygen, ozone, weak acids, and bases. Its useful temperature range extends from −65 to 300°F, and it has high tensile strength and wear resistance. Ethylene propylene swells severely in petroleum fluids; therefore, it normally cannot be recommended for such service.

Fluorocarbon rubber is better known by its trade names: Viton and Fluorel. It probably comes closest to being the ideal material for seals because it has good resistance to a wide range of fluids, is tough and wear resistant, can be used at temperatures from −20 to 400°F for long periods, and has good resistance to ozone and aging. The initial cost of fluorocarbon seals is considerably higher than that of similar seals made of nitrile. Nevertheless, it is the most cost-effective material for many seals because its low-compression set and high-temperature resistance significantly increase the time between replacement.

Silicone rubber has a wide temperature range. For instance, some silicone compounds remain flexible below −175°F, and some resist temperatures to 700°F for short periods. The temperature range for standard, off-the-shelf silicone is −65 to 350°F.

Silicone compounds also have excellent resistance to aging and ozone, and they generally have outstanding compression set properties, but they have poor resistance to most petroleum fluids, although they can be used with high-aniline-point oils. Also, their tensile strength and abrasion resistance are inferior to those of most other elastomers. These limitations make silicones poor candidates for dynamic seals.

Fluorosilicone compounds have almost as broad a temperature range as silicones, extending from about −100 to 300°F. Unlike silicones, however, they also have good resistance to petroleum fluids. But they are seldom recommended for dynamic seals because they have low tensile strength and poor abrasion resistance. High cost is a distinct disadvantage of fluorosilicones: up to 15 times the cost of nitrile.

Phosphonitrilic fluoroelastomer (PNF), is a polymer whose temperature range and physical properties are similar to those of fluorosilicones, but it is a tougher material, making it suitable for many dynamic applications. Its compression set characteristics, however, are inferior to those of fluorosilicones.

How seal materials compare

Property	Nitrile	Butadiene	Butyl	Epichlor-hydrin	Ethyle propyl
Resistance to:					
Weather	F	F	G-E	E	E
Ozone	P	P	G-E	E	E
Water/steam	F-G	F-G	G	F	E
Acids	F	F-G	G	F-G	G
Hydrocarbons	E	P	P	E	P
Polar fluids	F-G	G	E	F	E
Heat	G	F	G	F-G	E
Cold	G	G	G	G-E	G-E
Tensile strength	G-E	E	G	G	G-E
Tear resistance	F-G	G-E	G	G	G-E
Abrasion resistance	G	E	F-G	G	G-E
Compression-set resistance	G-E	G	F-G	P-F	G-E
Dynamic properties	G-E	F	F	G	G-E
Flame resistance	P	P	P	F-G	P
Impermeability	G	F	E	G-E	G
Electrical resistance	F	G	G	F	G

final application and cost. Minor changes in composition can cause major changes in properties.

Thermal factors include temperature extremes and variations, and cyclic frequency of the variations.

Chemical resistance to any specific agent can be obtained by proper formulation.

Weatherability is important for sealants exposed to outdoor service conditions.

Mechanical properties of importance include strength, elongation, compressibility, modulus of elasticity, tear resistance, and fatigue resistance.

Abrasion resistance is usually highest among the flexible sealants, especially urethanes and neoprenes.

Adhesion depends largely on the interaction between the sealant and the surface to which it is applied.

Electrical characteristics vary widely among sealants. Proper formulation can to a large extent control dielectric strength, dielectric constant, volume and surface resistivities, and dissipation factor.

Flameproof sealants are available for hazardous locations.

Nontoxic formulations are available for equipment in contact with foodstuffs.

Repairability is important in applications where the sealant may be broken during service. Some sealants, especially the nonhardening formulations, are easily replaced. ■

Aflas is a copolymer of tetrafluoroethylene and propylene. It is finding a place in certain oil-field applications because of its resistance to hydrogen sulfide, amines, acids, and steam. Claimed temperature resistance is up to 570°F in some situations.

Butadiene is a synthetic having properties similar to those of natural rubber. It has the same vulnerability to petroleum fluids and aging that limit the usefulness of natural rubber for seal applications.

Epichlorohydrin is a material with good resistance to petroleum fluids and ozone, and a recommended temperature range of −40 to 300°F. However, its compression set at 300°F is poor.

Kalrez is a series of perfluoroelastomers that have found a place where chemical or temperature requirements justify a high-cost seal. A temperature range extending to 500°F is claimed for most compounds.

Polyacrylate has outstanding resistance to petroleum fluids, oxidation, ozone, sunlight, and temperatures to 325°F in hot oil. One critical polyacrylate limitation is poor low-temperature performance (generally limited to −20°F). Compression set and water resistance also fall below the performance of most other elastomers, and cost is higher than that for nitriles.

Polysulfide rubber, also known as Thiokol, has remarkable resistance to a wide variety of solvents, including ethers and other solvents or solvent mixtures that cannot be sealed with any other elastomer. It also has outstanding resistance to stress cracking, oxygen and ozone, and good low-temperature flexibility. Unfortunately, its heat resistance, mechanical strength, and compression set leave much to be desired.

SBR, GRS, or Buna-S rubber has only a limited role as a seal material. Like natural rubber, SBR has poor resistance to petroleum fluids, ozone, and weathering. When properly compounded, however, its abrasion resistance is excellent. The primary market for SBR is seals in the automotive industry, because it has good resistance to nonpetroleum fluids used in brake and power steering systems. SBR's resistance to aging is similar to that of nitrile.

Polyurethane is produced in three basic forms: castable, millable, and thermoplastic. It is particularly noted for high tensile strength, outstanding wear and abrasion resistance, and for excellent extrusion resistance. It also holds up well in petroleum fluids. This combination of properties makes the polyurethanes invaluable for heavy duty hydraulic piston and rod seals.

The primary limitation of polyurethane is its loss of strength and memory at higher temperatures. It is seldom recommended for service above 200 to 225°F, and in steam and hot water the top limit is 190°F. Compression set is also poorer than that of most other seal compounds, so polyurethane seals are often designed to be pressure assisted or to be activated by a more resilient member.

Polyester, such as Hytrel, has outstanding chemical resistance. It is tough and abrasion resistant, much like urethane, but it also has poor compression set. In most seal applications, it must be activated by a material with better memory. Polyester, and formulations of it, are useful for molded packings in heavy-duty applications where temperatures or fluids are too severe for polyurethane.

Fluorocarbon	Fluorosilicone	Natural rubber	Neoprene	PNF	Polyacrylate	Polyester	Polysioprene	Polysulfide	Polyurethane	SBR	Silicone
E	E	F	E	E	E	E	F	E	E	F	E
E	E	P	G-E	E	E	E	P	E	E	P	E
F-G	F	F-G	F	F	P	F	F-G	F	P	F-G	F
E	F-G	F-G	F-G	P	P	F	F-G	P	P	F	F-G
E	G	P	F-G	E	E	E	P	E	E	P	P-G
P-G	P	G	F	F	P	P	G	G	P	G	P
E	G	F	G	E	E	G	F	P	F	F-G	G-E
P-F	E	G	F-G	E	P	F-G	G	G	G	G	G-E
G-E	F	E	G	F	F	E	E	F	E	G-E	P
F	P	G-E	F-G	P-F	F-G	E	G-E	P	G-E	F-G	P
G	P	E	G	F	G	E	E	P	E	G	P
E	G-E	G	F	G	F	P	G	P	F	G	G
G-E	P	E	F	F	F	E	F	F	E	G	P
E	G	P	G	G	P	P	P	P	P	P	F
G	P	F	G	G	E	F	F	E	E	F	P
F	E	G	F	F-G	F	E	G	F	E	G	E

Lubricants and bearings

Operating most efficiently is a machine's first step to maintaining productivity.

Bearings permit smooth low-friction rotary or linear movement between two surfaces. Bearings employ either a sliding or rolling action. In both cases, there is a strong attempt to provide enough lubrication to keep the bearing surfaces separated by a film of oil or other lubricant. The absence of physical contact provides most bearings with long service lives.

Bearings based on rolling action are called rolling-element bearings. Those based on sliding action are called plain bearings. Because there is more variation in the ways that plain bearings are lubricated, they are also referred to by the lubricating principle involved. For example, comparisons often are made between roller bearings and "fluid-film bearings," a class of plain bearings.

Plain bearings are generally less costly than rolling-element bearings. This is especially true in mass-production quantities. In moderate and small quantities, roller bearings are more competitive from a price standpoint, especially if a plain bearing requires special lubrication or demands special designs that cannot be supplied off-the-shelf.

Terminology differs somewhat for the two types of bearings. For example, a bearing can carry loads along its axis of rotation or perpendicular to its axis of rotation. For both types of bearings, those carrying loads along the axis of rotation are referred to as thrust bearings. Rolling-element bearings carrying loads perpendicular to the rotational axis are called radially loaded bearings. Plain bearings carrying such loads are usually called journal bearings or sleeve bearings.

Bearings are evaluated on the basis of how much load they can carry, at what speeds they can carry this load, and how long they will serve under the specified conditions. Friction, start-up torques or forces, ability to withstand impact or harsh environments, rigidity, size, cost, and complexity also are important design considerations.

Loads

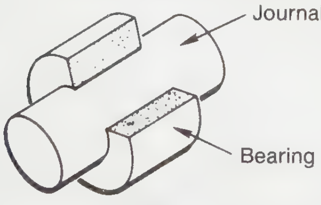
Load and operating speed affect bearings. Service life is determined statistically from tests of numerous samples, and is generally selected on the basis of a 10% failure rate (90% reliability). The result is the so-called B_{10} or L_{10} life.

Hydrodynamic and hydrostatic bearings, however, operate with infinite service life below some critical value of load and speed. With a self-acting, oil-lubricated (hydrodynamic) sleeve bearing, load capacity increases linearly with speed since rotation builds the supporting lubricating film.

For the extremely pressurized (hydrostatic) sleeve bearing, there is a particular load capacity for infinite life, and this capacity is essentially un-

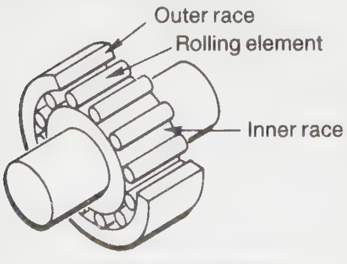
BEARING TYPES

Plain bearings have sliding surfaces. This action is used for rotation, translation, and radial and thrust loading. When the bearing materials are properly selected, the bearing may run without a lubricant, but usually at relatively low load or speed. Lubricants, which can be almost any noncorrosive liquid, increase operating load and speed.



PLAIN

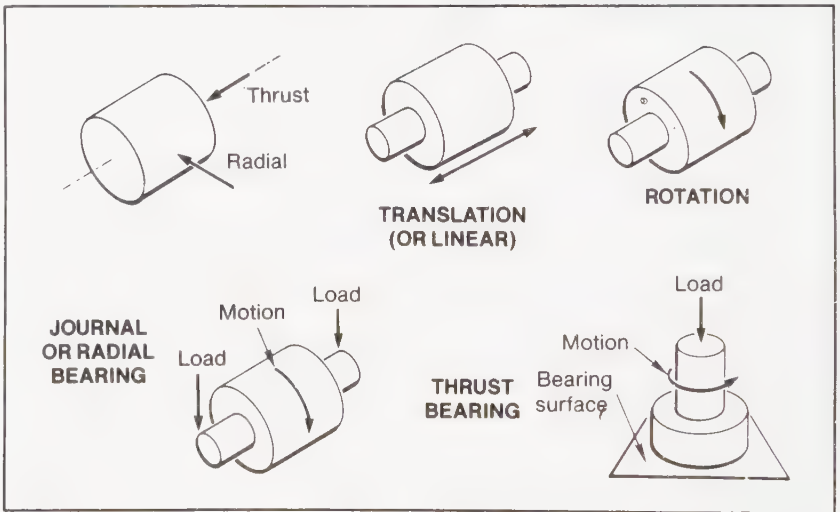
In rolling-element bearings, the rolling elements are housed in a separator or cage. The rolling elements' lubricant reacts in a manner termed elastohydrodynamic (EDH) action. Although all bearings are designed for specific end-uses, this is especially true of rolling-element bearings which are chosen carefully to suit the intended application.



ROLLING-ELEMENT

LOADING AND MOTION

Bearings accommodate rotational or translational motion. If the motion is not specified, it is generally assumed to be rotational. Translational bearings, called linear bearings, are loaded perpendicular to the direction of motion. In rotational bearings, the load can be either perpendicular to the axis of rotational (radial loads) or coincident with the axis of rotation (thrust loads).



Full Line Guide to DU®, DX™, GAR-MAX® & GAR-FIL® Bearings, & MULTIFIL™ 426 Bearing Tape

Toll free
1.800.222.0147

Garlock Bearings Inc.

Coltec Industries

Coltec Industrie

DU

*steel-backed
self-lubricating
bearings*

The one and only! From dry start-ups to high speeds, it's the bearing of choice.

Loads: PV's to 50,000 psi-fpm for continuous operation; 100,000 psi-fpm for short term operation.

Speeds: to 1000 fpm without lubrication; 2000 fpm with lubrication.

Temperatures: from −328°F to +536°F.

Compressive Strength: 44,000 psi.

Static Load Capacity: 20,000 psi.

Motion: rotating, oscillating and sliding motion.

Structure:

(1) steel backing for high load carrying capacity; thin, compact design; excellent heat dissipation; and dimensional and structural rigidity.

(2) porous bronze innerstructure is comprised of a layer of bearing quality powdered bronze sintered onto the steel backing and impregnated with a homogeneous mixture of PTFE and lead. This superior innerstructure assures maximum thermal conductivity away from the bearing surface and provides a reservoir of lubricant.

(3) PTFE-lead overlay provides a low friction bearing surface.

The science of DU bearings.

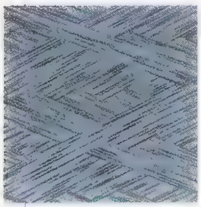
Our high performance DU self-lubricating bearing has a greater application range than any other self-lube material, and offers a combination of properties and capabilities unsurpassed by any product of its kind. With DU, Garlock combines the advantages of many conventionally lubricated metallic bushings— particularly high loading capacity and dimensional rigidity—with the design freedom of self-lubricating materials, including the ability to operate well beyond the scope of ordinary lubricants.

DU bearings provide a continuously restored, low friction bearing surface. In non-lubricated applications, an initial transfer coats the mating surface, forming an oxide-type lubricant film. As this transfer film is depleted,

Free DU® bulletin. Ask for #781-C.

Circle 667

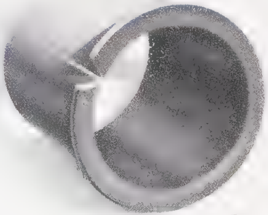
GAR-MAX® tough! An ideal surface when lubrication levels vary and/or contaminants are a problem.



Circle 668

Garlock
Bearings.
We put se
lubricatin
bearing te
work
for you.

Recent advances in self-lubricating bearings have given designers, manufacturers and end users a proven way to reduce unit size, weight and costs while impro ing reliability and performance.



DU®

©Copyright 1991 Garlock Bearings Inc. All rights reserved. Printed in U.S.A.

ings Inc.

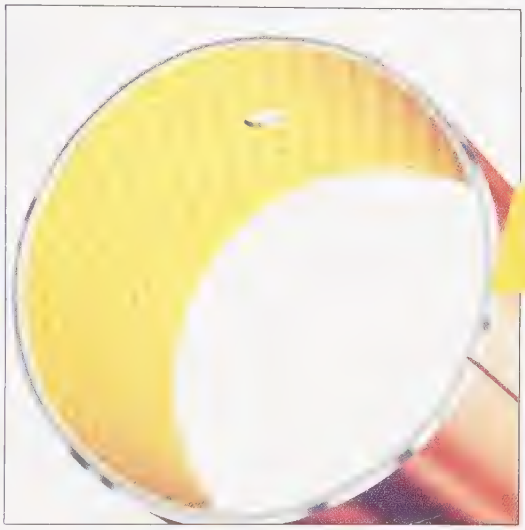
hnology to

Garlock Bearings has long been recognized as the leader in our field...through research, development, testing and distribution.

Today, Garlock Bearings offers the design engineer an extremely effective means of reducing or eliminating the need for lubrication ...and for providing an even more reliable assembly in applications which retain partial or full lubrication. By combining the excellent frictional properties of PTFE (polytetrafluoroethylene) and other low friction compounds with high strength structural materials, we can meet the most demanding requirements.

the relative motion of the mating parts continues to draw material from the porous bronze innerstructure. (When conditions are severe, the feed of lubricant increases.) The peaks of bronze coming in contact with the mating surface generate localized heat which, due to the high thermal expansion rate of PTFE, forces additional lubricant to the bearing surface. The relative motion of the mating parts wipes the lubricant over the entire interface, continuously restoring the low friction surface film for thousands of hours of high performance operation.

DU bearing material is available prefinished in 1/8 in. to 32 in. sizes; as thrust washers, strips, and in special configurations. Millions of these units are purchased annually for virtually every bearing-using industry!



DX
prelubricated bearings

Loads: PV's to 80,000 psi-fpm.

Speeds: to 100 fpm.

Temperatures: from -40°F to +260°F.

Static Load Capacity: 20,000 psi.

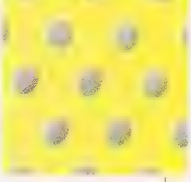
Structure: steel backing, porous bronze innerstructure, acetal resin overlay.

Overview: Standard DX bearings feature unique grease pockets. A trace of lubricant upon installation is all that is needed for the life of most assemblies.

DX is ideal for conditions of marginal lubrication which do not favor the formation of an oil film, including oscillating or fretting conditions, high loads, low speeds, frequent start/stop applications, or starting under load. These prelubricated bearings operate with less friction and wear than bronze surface bearings. With periodic relubrication, their useful life can be extended indefinitely.

DX bearings are recommended for applications involving intermittent operation or boundary lubrication, especially where lubrication cannot be supplied continuously or repeatedly. If desired, the DX material can be sized in place by boring or reaming.

Unmistakable! Bright yellow color and a superior grease retention system.



Circle 669

Free DX™ bulletin. Ask for #811-C.

GAR-FIL® filament wound, composite self-lubricating bearings

Loads: PV's to 35,000 psi-fpm.
Speeds: to 500 fpm.
Temperatures: from -320°F to +400°F.
Compressive Strength: 55,000 psi.
Static Load Capacity: 20,000 psi.
Structure: high strength, filament wound, glass-epoxy backing; filled PTFE tape liner bearing surface.
Overview: For high load applications; high or low speed operation; in dry, or partial to fully lubricated service.

GAR-FIL's tough composite structure consists of epoxy-impregnated, wound glass fibers oriented to provide the radial and axial strength required to support high bearing loads. A proprietary filled PTFE liner (for long life *without* lubrication) is securely bonded to its surface.

These bearings provide excellent wear resistance and tolerance of surface fatigue in most applications involving frequent or continuous use, including cyclic motion. In low speed, high load applications, GAR-FIL bearings have a coefficient of friction between 0.02 and 0.25, depending on factors affecting performance. The damage-resistant, borable surface also can tolerate dirty environments since some foreign matter can be embedded in the liner without causing harm to the shaft or bearing. The bearing surface can be bored to control initial running clearance or to correct minor misalignment.

GAR-FIL bearings can be used in the presence of a wide range of corrosive and non-corrosive fluids; including mild acids, alcohol, oils and detergents.

MULTIFIL™ 426 bearing tape

This filled PTFE bearing tape was especially developed for machine tool ways, gibs and other sliding applications. Easily applied to any clean, rigid substrate, MULTIFIL 426 bearing tape helps to eliminate stick-slip, chattering, scuffing, and galling due to lube breakdown, uneven wear and override. Available in standard thicknesses of .015″, .030″, .060″, .090″, and .125″ in standard widths of 12″ and 24″, and lengths up to 100 ft.

MULTILUBE® bearings

Economical MULTILUBE self-lubricating bearings are a unique combination of lubricants dispersed throughout thermoplastic base resins. The improved bearing surface lubricity permits use at far higher PV levels than possible with other plastic bearings, without creating interface temperatures or surface shearing problems that might cause rapid wear. Temperature range: -40°F to +200°F (250°F short term).

GAR-MAX® impact-resistant self-lubricating bearings

Loads: PV's to 30,000 psi-fpm.
Speeds: to 25 fpm.
Temperatures: from -320°F to +325°F.
Compressive Strength: 60,000 psi.
Static Load Capacity: 30,000 psi.
Structure: rugged, filament wound, glass-epoxy backing; bearing surface of wound PTFE and high strength fibers encapsulated by an epoxy resin.
Overview: The most shock resistant self-lubricating bearings available today; ideal for tough, pivoting applications subjected to impact loadings and/or structural misalignment.

GAR-MAX features the same high strength backing of GAR-FIL bearings, plus a patented combination fiber surface liner which comprises a controlled filament wound pattern of both PTFE and high strength fibers. These materials are braided together to form a cord which is wound and fully encapsulated by an epoxy resin that has been further enhanced with a self-lubricating filler to provide an exceptionally wear resistant bearing surface.

Long-term field testing in actual bearing applications has shown that GAR-MAX bearings exhibit greater resistance to impact and shock loads than other types of filament wound composite bearings. Also—they can tolerate a high degree of shaft misalignment, and even more abrasive contaminants than GAR-FIL bearings.

Like GAR-FIL, our GAR-MAX self-lube bearings offer a thermal expansion rate similar to that of steel, for maximum dimensional stability and positive housing retention, even at elevated temperatures. GAR-MAX is well-suited for agricultural, construction and other off-the-road vehicles and equipment.

GAR-FIL and GAR-MAX bearings are available in standard ID sizes from 3/4 to 5 in., with a wall thickness of 1/8 or 1/4 in. Metric and special sizes above 5 in. ID can be furnished. Standard metric sizes are available from 20 to 150 mm with a 2 -1/2 mm or 5 mm wall.

Custom self-lube bearings.

Our materials development and evaluation program covers a wide range of specialized products and materials, including modified and un-modified nylons and acetals, polyimides and other filled and unfilled thermoplastic resins.

Garlock engineers will be glad to assist you.

Call us.
1-800-222-0427.

IMPORTANT: Popular sizes of the bearings described in this bulletin are available from stock.

The information in this bulletin should be used as a guide for your consideration, investigation and verification. It does not constitute a warranty or representation, and we assume no legal responsibility or obligation with respect thereto and the use to which such information may be put.

Garlock Bearings Inc.

Coltec Industries

700 Mid Atlantic Parkway
Thorofare, NJ 08086
Phone: 1-800-222-0147
FAX: (609) 848-5115

affected by speed — although at times there may be some hydrodynamic or speed-dependent contribution to load capacity.

If loads exceed the infinite-life value, the surfaces are assumed to come into rubbing contact, thereby setting up a condition of boundary lubrication. This condition often leads to accelerated wear and failure. However, bearings can be designed to operate satisfactorily in the boundary mode.

As a result of these interactions, rolling-element bearings are less sensitive than plain bearings to load variations. And because they do not rely on velocity effects to maintain a fluid film, they are well suited to supporting heavy load at low speeds. Fluid-film bearings tend to be a better choice if load increases with an increase in speed or if the load is dynamic. On the other hand, pulsating heavy loads on stationary rolling-element bearings can cause brinelling.

Both rolling-element and plain bearings can be vulnerable to severe impact loads. Often a case is presented that rolling-element types are more vulnerable because of their line or point contact and resulting high contact stress. The fluid film in plain bearings is said to provide a better "cushion" for impact. More realistically, however, resistance to impact for both types depends upon reserve capacity. Either type can be designed to sustain high impact.

Deflection

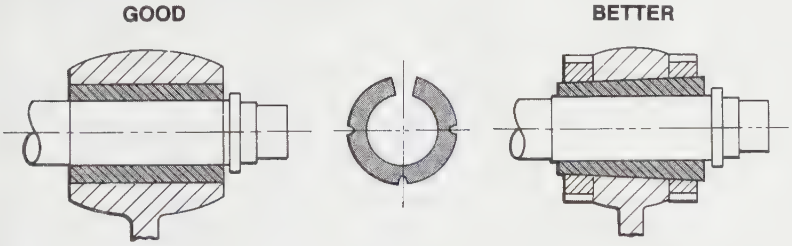
At light loads an externally pressurized sleeve bearing tends to be stiffest, followed by rolling-element bearings, and self-acting sleeve bearings. As loads increase, the rolling-element bearing deflection exceeds that of the self-acting sleeve bearing. With a further increase in load, the deflection of the externally pressurized bearing exceeds that of the self-acting sleeve bearing. Thus, the least rigid bearing at light loads becomes the most rigid at heavy loads. Stiffness of the rolling-element bearings could be increased by a switch to roller bearings or preloaded, angular-contact ball bearings.

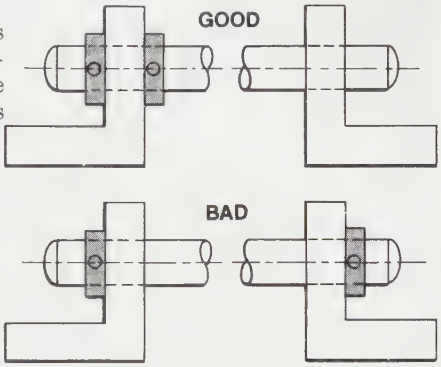
Deflection at the bearing — or at the load point in the bearing-shaft system — is often important, especially in machine tools and precision instruments. Deflection of overhung loads can be particularly critical since the stiffness at the loading point is sometimes less than 10% of the basic bearing stiffness.

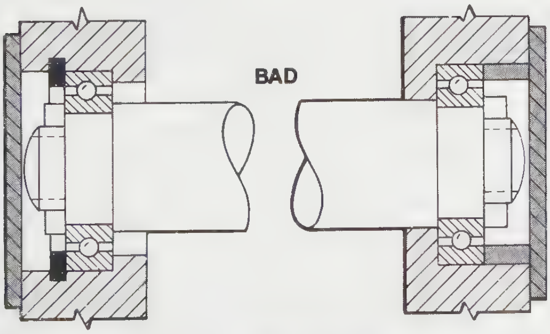
Self-lubricating bearings: Boundary-lubricated or self-lubricated

DESIGNING BEARING MOUNTINGS

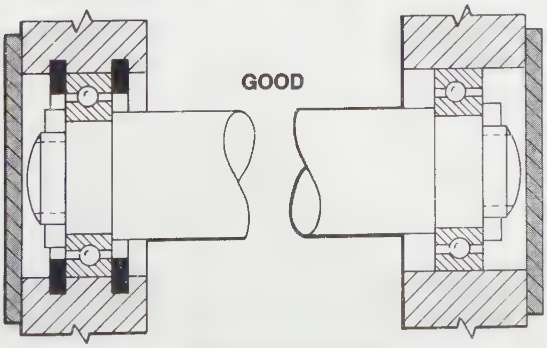
Overrestriction is one of the more common design errors. Bearing mountings must accommodate both thermal expansion and wear of components, yet maintain axial alignment. Also, the mountings should be inexpensive to manufacture and allow access for lubrication or bearing replacement. The following tips illustrate how to improve mountings.



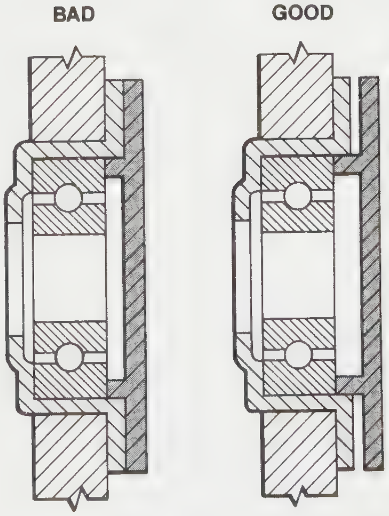




With bearings mounted with no provision for axial shaft expansion, distortion or seizing can occur. In addition, holding the close tolerances involved is expensive.



A better design fixes one of the bearings with split rings and locates the other in a smooth bore so it can float axially.



Covers on bearing boxes should be designed with a gap between the flange and the box to ensure positive axial retention.

bearings provide high stiffness once they have been loaded heavily, but they are the least stiff under light and moderate loads. This bearing type can be troubled by stick-slip operation and by erratic torque response from variation in surface lubrication.

Sleeve bearings: While the shaft in a fluid-film bearing does deflect with load, this movement is predictable. Although the running position of a machine spindle supported by sleeve bearings may be quite different from the static position, the change can be accounted for, and the spindle operates smoothly in the deflected state.

Rolling bearings: These usually provide more precise shaft positioning than journal bearings. Preloaded angular-contact and tapered roller bearings are particularly rigid and are commonly used in machine tools. Shaft position is more predictable under varying loads. Running and static positions are nearly the same. Where extreme precision is required, rolling-element bearings may exhibit objectionable elastic deflection and excessive fluctuations from variations in element roundness. Here, externally pressurized bearings may be required.

Hydrostatic bearings: This type provides minimum deflection and the most precise shaft positioning, while operating smoothly. Machine tools using this type of bearing can grind parts round to within 2 μin. with a 1-μin. surface finish. The pressure system can be either gas or liquid. Gas systems are often used in lightly loaded applications, while liquid systems are normally used for heavily loaded systems.

Friction

Torque required to put a bearing into motion from rest is usually higher than the torque required to keep it running once it starts. Starting friction, therefore, has an important influence on the power required in a drive system.

Externally pressurized bearings have very low starting torque. Roller bearings have a low starting torque and underpressurized sleeve (fluid-film) bearings have substantially higher starting torque. The coefficient of friction at start-up for self-lubricated bearings is highly variable. It may range from 0.04 to 0.16.

The fluid-film bearing has a high starting torque because it passes through boundary lubrication stages as it comes up to speed. Once running under a hydrodynamic film, the fluid-film bearing exhibits friction characteristics comparable to a rolling-element bearing.

At running speed, the externally pressurized bearing runs with low friction. Friction in a self-lubricating sleeve bearing is quite variable, depending upon the application.

Running friction for a rolling-element bearing is lower than its starting friction. If torque characteristics are critical to a design, starting and running frictional characteristics should be measured experimentally.

If a bearing must be started repeatedly under heavy load, rolling-element bearings offer a better choice than sleeve bearings. If the increased complexity is acceptable, externally pressurized (hydrostatic) bearings are the best choice of all. If starting load is light and load increases gradually with speed, the conventional hydrodynamic sleeve bearing usually is preferred.

Noise

When a machine is subjected to a noise-reduction program, bearings are normally involved. Even if bearings are not generating noise, they may be concerned with noise transfer.

Generally, rolling-element bearings are noisier than fluid-film bearings. Minor inaccuracies in rollers or raceways can generate sounds that are amplified by the machine structure. Improving bearing quality can reduce this effect.

Fluid-film bearings under steady radial load generally do not produce noise. However, if this type of bearing is reversed frequently, it can generate considerable noise if it doesn't have enough lubricant to fill the bearing. Fluid-film bearings running unstable in a whirling mode can also produce noise.

Size

Bearings that require a separate pressurized lubrication system need more space than self-lubricating types. The relative space required at the actual load-support point is not clear, because a pressurized bearing can be more compact than self-contained bearings at the load-support point.

For self-contained bearings, the sleeve bearing requires less radial space than a rolling-element bearing; however, the sleeve bearing needs slightly more axial space. Needle bearings require about as much space as journal bearings.

Cost

Hardware costs: In high-volume lots, sleeve bearings and bushings are considerably less costly than rolling-element bearings. In mid-range volumes, prices are comparable. For special designs in small quantities, sliding bearings are more costly than rolling-element bearings. Dry-film and boundary-lubricated bearings usually employ proprietary materials that are expensive. Powdered-metal bearings, however, are inexpensive.

Design costs: Rolling-element and dry-lubricated bearings normally require the least cost for end user. Manufacturers of rolling-element bearings can provide considerable cost-saving assistance by virtue of well-documented design manuals. Self-acting sleeve bearings, however, may require considerable end-user design effort except for light-duty applications experience. The behavior of externally pressurized bearings usually can be predicted by calculations, but considerable design effort may be required to verify the design completely.

Shop costs: Rolling-element bearings normally require precise housings and shafts and require fairly costly machining for products in which they are used. Sleeve bearings, in contrast, generally operate well with less finely prepared machine finishes. Many plain bearings operate satisfactorily with lathe-turned journals.

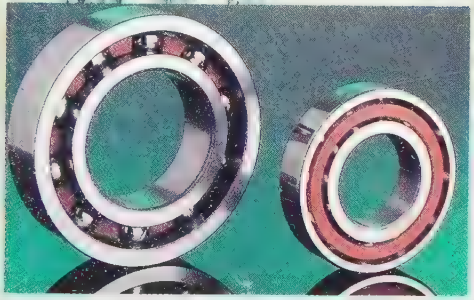
Maintenance costs: If the bearing lubrication is self-contained, maintenance costs are determined by sealing requirements. If there is full-pressure lubrication, costs may be determined by the amount of filtration needed. Generally, rolling-element bearings have the lowest maintenance costs because of lower lubrication requirements. The very minimum maintenance cost is associated with self-lubricating bearings — provided that they deliver sufficient service life.

Replacement costs: These costs depend more on the specific design than on the type of bearing. In general, however, sliding bearings are replaced more easily than rolling-element types. Both types can be damaged during installation if not handled properly. Sliding bearings can often be replaced quickly by machining from bar stock or by altering available stock sizes.

Cost of failure: Rolling-element bearings give ample warning that they are approaching failure (by virtue of increasingly noisy operation) and usually fail from mismounting, contamination, inadequate lubrication and misalignment. Sliding bearings, on the other hand, usually perform well up to moments before a violent failure.

If a rolling-element bearing fails at high speed, it is usually total and cata-

NHBB meets your tough bearing designs head-on.



***Machine Tool Spindle bearings** engineered and manufactured to exacting tolerances from a variety of materials, including ceramic balls.*

May We Build One For You?

NHBB is different. Our engineering capability sets us apart from the "off-the-shelf" bearing vendors. NHBB's world class engineering, R&D and testing departments invite you to submit your unique application. We'll meet the engineering challenge with our:

- *Advanced CAD/CAM capabilities*
- *Metallurgical, lubrication, testing and performance analysis laboratories*
- *Flexibility and quick reaction time for your special needs*
- *Commitment to your total satisfaction*

NHBB is your best source for custom engineered ***and*** standard bearing products.

SERVING:
Commercial and Military OEM's in Aerospace, Electronics, Medical and Machine Tool industries.

PRODUCTS:
Specialty Ball Bearings up to 6" outside diameter
Rod End and Ball Bearing Rod End
Spherical • Sleeve • Slotted Entry • Composite
Airframe • Miniature and Instrument • Duplex
Precision Mechanical Assemblies
Aerospace High Strength Bolts

NHBB®

New Hampshire Ball Bearings, Inc., Route 202 • Peterborough, NH 03458 • USA Headquarters • East Coast (603) 924-4100 • West Coast (818) 993-4100

COMPARING SLEEVE BEARING ALLOYS

Bearings operating with full-film lubrication theoretically never touch the shaft. However, bearings do start and stop, and some are required to operate with boundary lubrication, or no lubrication at all, for short periods. So, a bearing material must be selected on the basis of operating factors including load, speed, contamination, life, temperature, and the type and quantity of lubrication available.

Babbitts and cadmium materials are rated highest on compatibility for operation against steel shafts. Babbitts, soft low-melting alloys, are best in conformability and in embedding dirt. The harder materials such as the bronzes, aluminum, and silver carry heavier loads and offer better fatigue strengths.

Compatibility: A measure of the antiweld and antiscoring characteristics of a bearing material when operated with a given mating material. All journal bearings experience some metal-to-metal contact, if only during starting. During metal-to-metal contact, sliding surfaces rub on microscopic high spots. The friction developed at these points can produce localized welding, causing a seizing damage resembling scoring. Therefore, a good bearing material is one which will not weld easily to the shaft material.

	Hardness, room temp (Brinell)	Hardness, 300° F (Brinell)	Min shaft hardness (Brinell)	Load carrying capacity (psi)	Elastic modulus (1000 psi)	Maximum operating temp. (°F)	Compatibility*
Tin-base babbitt	20-30	6-12	130-170	800-1500	7-6	300	1
Lead-base babbitt	15-20	6-12	130-170	800-1200	4-2	300	1
Three-component bearings, babbitt surfaced	—	—	200-300	2000-5000+		300	1
Cadmium base	30-40	15	200-250	1500-2000	8	500	1
Copper-lead	20-30	20-23	200	1500-2500	7.6	350	2
Lead bronze	40-70	40-60	300	3000-4000	14	450	3
Tin bronze	60-80	60-70	300-400	4000+	16	500+	5
Aluminum alloy	45-50	40-45	200-300	5000+	10.3	250	4
Silver (overplated)	25	25	300-400	5000+	11	500	2

*Arbitrary scale with 1 being the best material and 5 the worst

strophic. With a journal bearing, the effect is normally less drastic. Often, only a bit of polishing puts it back into service. However, sliding bearings can suffer catastrophic failure.

Sliding-bearing materials

Most bearings consist of a relatively limited number of alloys, porous metal, plastics, or other nonmetallics. No material is equally good with respect to all bearing requirements, so selection is a matter of judgment based on essential factors. Materials and processes are constantly raising and broadening the operating limits of all bearings, so existing designs can often benefit from periodic reviews of the latest state of the art.

Babbitts

Tin and lead-base babbitts are among the most widely used bearing materials. They have an ability to embed dirt and have excellent compatibility properties under boundary lubrication.

In small bushings for fractional-horsepower motors and in automotive engine bearings, babbitt is generally used as a thin coating over a steel strip. For larger bearings in heavy-duty equipment, thick babbitt is cast on a rigid backing of steel or cast iron. After machining, the babbitt layer is usually ⅛ to ½ in. thick.

Compared to other bearing materials, babbitts generally have lower load-carrying capacity and fatigue strength, are slightly more costly, and require a more complicated design. Also, their strength decreases rapidly with increasing temperature. These shortcomings can often be avoided by using an intermediate layer of high-strength, fatigue-resisting materials between the steel backing and the thin babbitt surface layer. Such composite bearings frequently eliminate any need for alternative materials with poorer compatibility characteristics.

Tin babbitt: These materials are composed of 80 to 90% tin, with about 3 to 8% copper and 4 to 14% antimony added. An increase in the copper or antimony increases hardness and tensile strength, and decreases ductility. Increasing the percentage of these hardening alloys above this range decreases both cracking resistance and fatigue strength.

Of the three tin-base babbitts, SAE Grade 11 (or the ASTM Grade 3 with 6¼% copper and 7¼% antimony) has extensive industrial use, and the SAE 12 alloy is most widely used in automotive applications. Tin babbitt is used in smaller volume than lead babbitt because of the higher cost of tin. However, it is frequently preferred for industrial applications because of its higher corrosion resistance, easier bonding, lower tendency for segregation, better high-temperature characteristics, and lower tendency to pickup on a shaft under conditions of poor lubrication.

Lead babbitt: Generally, these compositions range from 10 to 15% antimony and up to 10% tin in combination with the lead. Lead babbitts based on lead-antimony-tin alloys have a structure consisting of hard antimony-tin crystals in a relatively soft high-lead matrix. SAE 14 alloy, containing 10% tin for improved corrosion resistance, is popular for many industrial, railroad, and automotive applications. SAE 13 alloy is used where a softer babbitt is desired; but SAE 15 arsenical alloy, with its better high-temperature hardness, is the most widely used of the three because it withstands higher loads and provides longer fatigue life in the automotive and diesel field.

Compared to tin babbitts, lead-base materials are less costly and have less tendency to score a shaft. With quick chilling to give a fine microstructure, thin surface layers for improved fatigue

Corrosion resistance: Important where lubricants are uninhibited industrial oils or where oils have antiwear compounds. Oxidation products from some lubricating oils can attack and corrode cadmium, lead, zinc, and some copper bearing alloys. Corrosion effects can be minimized by such modifications as applying a thin flash of indium over cadmium or lead alloys, or by adding tin to lead babbitt. Both tin and aluminum alloys are usually unaffected by oxidized oils.

Cost factors: Frequently the deciding factor in selection of a bearing material. Some materials cost more than others. Frequently, however, a thin layer of high-cost material can supply the necessary bearing characteristics while a low-cost backing material provides necessary structural strength.

Conformability & embeddability*	Corrosion resistance*	Fatigue strength*
1	1	5
1	3	5
2	2	2
2	5	4
2	5	3
4	4	2
5	2	1
3	1	2
3	1	1

Conformability: Ability to compensate for misalignment and to conform to other geometric errors. Good conformability is characteristic of metals with a low modulus of elasticity.

Load capacity: Largely, an experience factor related equally to design and lubrication, as well as to the strength and other performance properties of the material. Expressed in psi, it is a measure of the maximum pressure which a material can be to endure.

Fatigue resistance: Particularly important in applications where the load changes direction, such as in reciprocating automotive and aircraft engines. When a bearing material experiences a fatigue failure, cracks are initiated just below the surface of the material at the points of maximum shear stress. In babbitt, these cracks propagate at a right angle to the surface down to the bond with the backing material. Then they progress along the backing material and join other similar fatigue cracks. When sufficiently weakened, the bearing material begins to flake loose. Low-modulus materials are often used as thin overlays over strip steel to improve fatigue resistance.

Embeddability: Ability to absorb dirt and other foreign particles to avoid scoring and wear. Usually, in metallic bearing materials, good embeddability is found in materials with good conformability. This is not true in nonmetallic materials. Carbon graphite has a low modulus and good conformability, but its hardness gives it a poor ability to absorb dirt.

strength, and careful attention to bonding, lead babbitt gives excellent service and is used in much greater volumes than tin babbitt.

Bronzes and copper alloys

Dozens of copper alloys are available as bearing materials. Most of these can be grouped into five classes: copper lead, copper tin (sometimes called tin bronze), leaded bronze, aluminum bronze, and beryllium copper.

As a general rule in these alloys, a higher lead content promotes compatibility with soft alloy shafts and reduces friction in low-lubrication conditions (start-up, for example) while slightly sacrificing wear resistance. Thus, copper lead and leaded bronzes are often used where compatibility outweighs the effects of lower mechanical properties. Other alloying elements are added to copper to tailor an alloy for user requirements based on load capacity, bearing strength, hardness, wear resistance, and fatigue strength.

Compared to the softer babbitts, copper-alloy bearings provide greater load capacity, better high-temperature operation, greater wear resistance, but poorer scoring resistance.

Copper lead: Since lead is practically insoluble in copper, a cast copper-lead microstructure consists of lead pockets in a copper matrix. These pockets of lead serve as reservoirs for maintaining a continuous lead film on the bearing surface.

With either continuous casting or powder-metallurgy techniques, a steel backing is used with copper-lead bearings for increased strength. These bearings are also frequently used with a babbitt overlay in a three-layer construction. The hardness of copper-lead materials is similar to that of babbitt at room temperature, but is higher at temperatures approaching 300°F. Corrosion of either the lead or copper can be minimized by additives in high-quality automotive and industrial lubricating oils.

Copper-lead systems are used for diesel engines on trucks and off-road vehicles, although aluminum alloys are frequently specified for greater corrosion resistance at a sacrifice of compatibility. Copper lead is used in moderate load and speed applications, such as electric motors, turbine engines, and generators.

Leaded bronze: The 4 to 10% tin content in leaded bronze increases strength, maximum load capacity, improves fatigue resistance, and increases hardness above what is available with simple copper leads. Zinc is sometimes used as a replacement for tin, and nickel (or nickel or silver) is often added to improve corrosion resistance and toughness.

Leaded bronzes have better compatibility than tin bronze because the spheroids of lead smear over the bearing surface under conditions of inadequate lubrication. These alloys are generally a first choice for intermediate loads and speeds. They are used in machine tools, home appliances, farm machinery, and pumps.

C93200 alloy is currently the standard cast-bronze bearing material with many suppliers. The 80-10-10 SAE C93700 phosphor bronze is also popular. Its relatively high hardness and good impact resistance make it widely used in steel plants for such applications as roll-neck bearings. It is also used in lathes, instruments, household appliances, diesel rocker-arm bushings, automotive piston-pin bushings, pumps, and trunnion bearings.

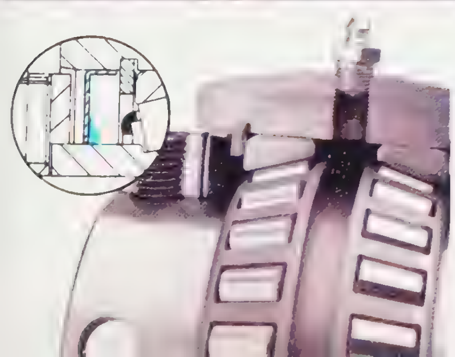
Softer C93800, with its higher lead content, is sometimes preferred because it offers better compatibility characteristics and good performance where lubrication is doubtful. It is widely used for diesel engine bearings, in cranes, and in railway and earthmoving equipment. It has good antiscoring properties with soft shafts.

NEW DODGE® TYPE E-XTRA™ BEARING.
ONE BEARING. ONE SEAL. VIRTUALLY ANY ENVIRONMENT.

From the manufacturer of the *original* Type E, now a single bearing that can withstand both dusty or damp environments. The new DODGE® Type E-XTRA™ tapered roller bearing has a new seal that helps eliminate contamination problems. The positive contact "R" Seal in the DODGE Type E-XTRA bearing conforms to the TIMKEN cone, permits grease to purge and effectively constrains entry of contaminants into the bearing.

Laboratory test results prove that the DODGE Type E-XTRA bearing, with its metal-shielded, land-riding, contact seal, equals or exceeds competitive "Type E" bearing seals in both environments.

The new DODGE Type E-XTRA bearing gives you better performance, better life – for better value. DODGE Type E-XTRA case-carburized races and rollers have hardened outer



surfaces to resist wear, resulting in excellent load handling and longer life. The softer, ductile interior absorbs shocks and resists crack propogation. Plus the DODGE SPRINGLOK® 65° setscrew locking system provides superior clamping.

For superior operation in virtually any environment, specify the new DODGE Type E-XTRA bearings. For more information, see your DODGE distributor or call 1-803-297-4800

© Reliance Electric Company, 1992

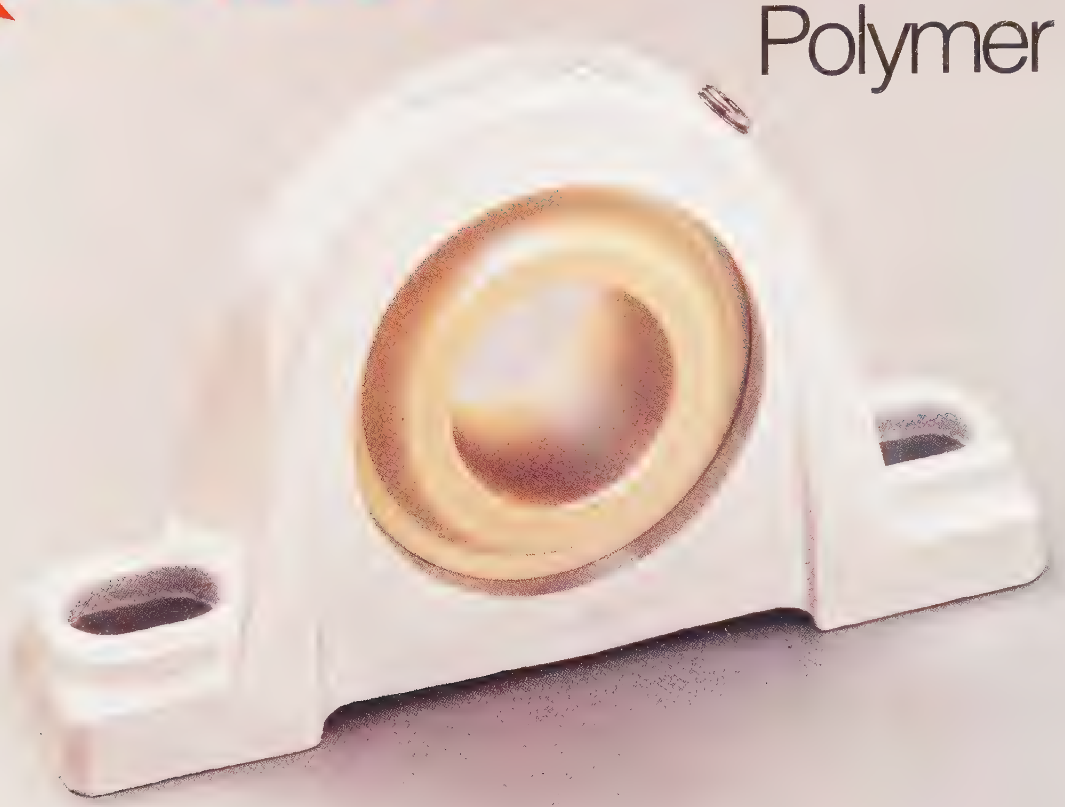
DODGE®

Move [illegible] with the leader.™

RELIANCE
ELECTRIC

NEW

DODGE® E-Z KLEEN® Sleeve Bearing with Polymer Inser



Easy washdown after splashdown.

U.S. Patent # 4973

With the new sleeve bearing you get all the features of the DODGE E-Z KLEEN bearing with housings coated with *Teflon** plus the added chemical and corrosion resistant polymer sleeve (PS) insert. The polymer sleeve is self lubricated for a maintenance-free environment.

- Corrosion and Abrasion Resistant
- Polymer Sleeve Resists Fungus and Bacteria Growth
- Quiet Operating Characteristics—Excellent Sound Dampening
- Subzero Ambient Temperatures Down to –40°F
- Can Operate in Wet Environments
- Conforms to FDA/USDA Specifications
- Self-Lubricating Polymer Sleeve Insert
- Low Coefficient of Friction
- Wide Variety of Housing Configurations
- Available in All Popular Bearing Bore Sizes
- Anti-Rotation Device Prevents Rotation of the Polymer Insert within the Housing

* Registered trademark of DuPont Co.

Inserts—The domestically manufactured DODGE Standard E-Z KLEEN PS Bearing is installed in a housing that is coated with *Teflon* to produce a dependable rugged mounted unit. The Polymer Sleeve Inserts are designed to take the constant washdowns the food, chemical and processing industries require and conform to FDA/USDA specifications for food contact.

Anti-Rotation—An anti-rotation device prevents the insert from rotating in the housing under unbalanced load conditions.

Housings—The one-piece gray iron housing is specially machined to accommodate *Teflon* coating. The thickness of the coating is .003 ± .001 and is designed to resist abrasion, chipping and flaking in acidic or caustic environments. The *Teflon* coating conforms to FDA/USDA specifications for food contact.

Lubrication—No lubrication is required on E-Z KLEEN Sleeve Bearings.

DODGE E-Z KLEEN Bearings with housings coated with *Teflon* are suitable for meat processing and packing, dairy products, bottling, canning, vegetable and fruit processing, bakery and confection, cereal, seafood processing, frozen foods, and pharmaceutical and cosmetic industries.

E-Z KLEEN Bearings with housings coated with *Teflon* are available in standard height pillow blocks, 4-bolt and 2-bolt flanges.

DODGE®

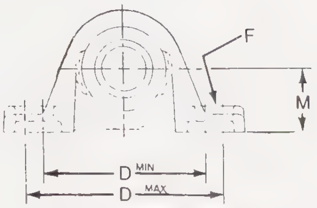
Move faster with the leader.™

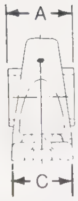
For more information call (803) 297-4800, FAX (803) 281-2318.
Or see your local DODGE Distributor in the Yellow Pages.

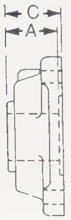
RELIANCE
ELECTRIC

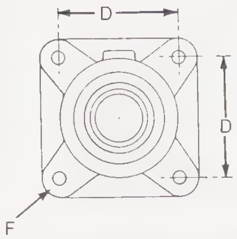
DODGE®

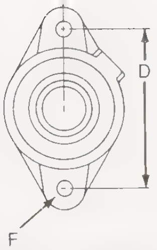
Dimensions:*











Shaft Sizes	Ring Size	A	C		D				F		M
			PB	Flg.	Pillow Blocks Min.	Pillow Blocks Max.	4-Bolt Flange	2-Bolt Flange	Bolt Dia. P.B	Bolt Dia. Flg.	Pillow Blocks
$\frac{3}{4}$	204	1	$1\frac{11}{32}$	$1\frac{1}{8}$	$3\frac{3}{8}$	$4\frac{3}{16}$	$2\frac{1}{2}$	$3\frac{17}{32}$	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{5}{16}$
1	205	$1\frac{1}{16}$	$1\frac{13}{32}$	$1\frac{7}{64}$	$3\frac{11}{16}$	$4\frac{1}{2}$	$2\frac{3}{4}$	$3\frac{57}{64}$	$\frac{3}{8}$	$\frac{7}{16}$	$1\frac{7}{16}$
$1\frac{3}{16}$ $1\frac{1}{4}$	206	$1\frac{3}{16}$	$1\frac{3}{4}$	$1\frac{7}{32}$	$4\frac{1}{4}$	5	$3\frac{1}{4}$	$4\frac{19}{32}$	$\frac{1}{2}$	$\frac{7}{16}$	$1\frac{5}{8}$
$1\frac{1}{4}$ $1\frac{7}{16}$	207	$1\frac{5}{16}$	$1\frac{3}{4}$	$1\frac{9}{16}$	$4\frac{11}{16}$	$5\frac{7}{16}$	$3\frac{5}{8}$	$5\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{7}{8}$
$1\frac{1}{2}$	208	$1\frac{9}{16}$	2	$1\frac{19}{32}$	$5\frac{3}{16}$	$5\frac{7}{8}$	4	$5\frac{21}{32}$	$\frac{1}{2}$	$\frac{1}{2}$	$2\frac{1}{8}$
$1\frac{15}{16}$	210	$1\frac{5}{8}$	$2\frac{1}{4}$	$1\frac{21}{32}$	6	$6\frac{11}{16}$	$4\frac{3}{8}$	$6\frac{3}{16}$	$\frac{5}{8}$	$\frac{1}{2}$	$2\frac{1}{4}$

Features	Functions	Benefits
Housing Coated with *Teflon*	Protects housing in washdown and chemical environments.	The coated housing resists oxidation, provides a "non-stick" surface for the food industry and is FDA/USDA approved.
Impregnated Polymer Sleeve Insert	Self lubricating.	No lubrication required and operates in wet or dry environments. Corrosive and chemical resistant and is FDA/USDA approved.
Corrosion Resistant Anti-Rotation Device	Locks the Polymer Sleeve Insert to the housing.	The stainless steel and polymer device prevents the insert from rotating in the housing due to unbalanced or eccentric loads.
Polymer Sleeve Insert	Supports and positions the rotating shaft.	No thrust washer required.

Ring Size	Shaft Size	*Radial Load Ratings (Lbs.) at Various Revolutions per Minute												
		Up to 10	25	50	75	100	150	200	250	300	350	400	450	500
204	$\frac{3}{4}$	375	375	375	375	375	200	110	75	55	45	35	30	25
205	1	530	530	530	530	350	175	110	75	55	45	35	30	25
206	$1\frac{3}{16}$, $1\frac{1}{4}$	700	700	700	550	350	175	110	75	55	45	35	30	25
207	$1\frac{1}{4}$, $1\frac{7}{16}$	820	820	820	600	350	175	110	75	55	45	35	30	25
208	$1\frac{1}{2}$	1125	1125	1125	550	350	175	110	75	55	45	35	30	25
210	$1\frac{15}{16}$	1575	1575	1125	500	325	175	110	75	55	45	35	30	25

Operating Temperature Range: -40° to 100°F.
For loads and speed combinations not shown on this chart or thrust load capabilities contact DODGE Engineering, Columbus, IN.
Due to unknown loads on take-ups, E-Z KLEEN sleeve bearings are not recommended for use as a take-up bearing.
Commercial shafting tolerance is acceptable, however, a finish of 10-20RA will reduce bearing wear.
DODGE collars are available and should be purchased separately for shaft location.
Radial load ratings were established for normal operating conditions, the service life may be reduced due to harsh environmental conditions with excessive temperature, dirt and abrasive materials. Therefore, field testing is recommended to verify bearing operating performance under harsh environmental conditions.

For More Information:

For more information about DODGE E-Z KLEEN Bearings with housings coated with *Teflon*, consult your DODGE Sales Representative.

DODGE/P.O. Box 499/2 Ponders Court/Greenville, S.C. 29602-0499/803-297-4800/FAX: 803-281-2318

© Reliance Electric Company, 1991

Circle 275

RELIANCE ELECTRIC

DODGE

DODGE® E-Z KLEEN™ MOUNTED BEARINGS WITH HOUSINGS COATED WITH *TEFLON** AND CORROSION RESISTANT FLINGERS

MOUNTED BEARING DATA SHEET

The DODGE E-Z KLEEN Setscrew Mounted Bearings with housings coated with *Teflon and corrosion resistant flingers are designed for the wet washdown environment of the food and chemical industries. The *Teflon** coating offers increased housing longevity over standard, painted units where oxidation, washdown, and exposure to the weather (including heat, cold and ultra violet light) exist. *Teflon** coating offers excellent "non-stick" properties that are essential for the food industry during washdown. It is chemically inert and normally unaffected by chemical environments. For specific application requirements contact DODGE Engineering.**

General Description:

Inserts—
The domestically manufactured DODGE Standard E-Z KLEEN Bearing is installed in a housing that is coated with *Teflon** to produce a dependable rugged mounted unit. The ProGuard™ seals and corrosion resistant flingers provide additional protection for washdown and chemical environments. The 65° setscrew mounting provides ease of installation and excellent holding power. The inner race is case carburized to provide a hard surface for wear resistance and durability. Yet, the soft ductile core prevents the propagation of cracks. The short fiberglass reinforced nylon cage is flexible and strong providing long life and quiet operation. The through hardened outer race has an anti-rotation pin in the circumference as added protection to prevent the insert from rotating in the housing under unbalanced load conditions.

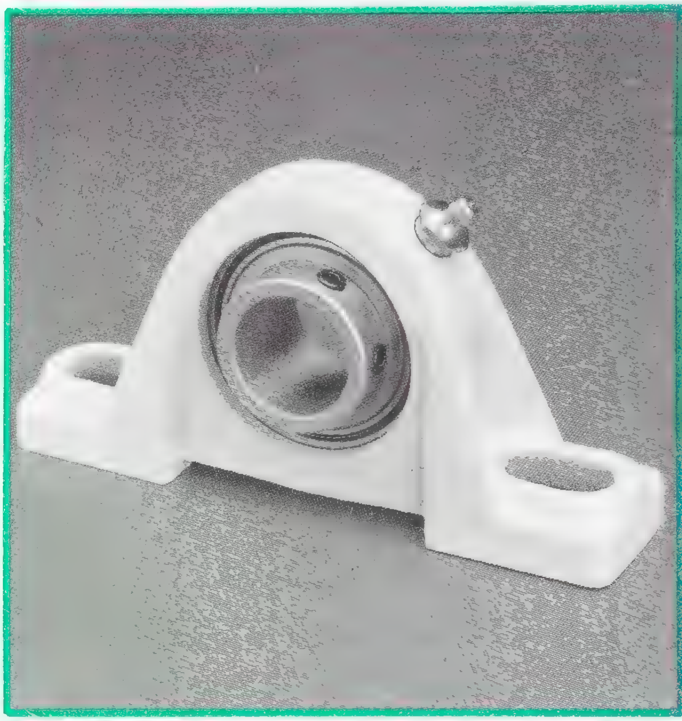
Housings—
The one-piece gray iron housing is specially machined to accommodate *Teflon** coating. The thickness of the coating is .003 ±.001 and is designed to resist abrasion, chipping, and flaking in acidic or caustic environments. The *Teflon** coating conforms to F.D.A. and U.S.D.A. specifications for food contact.

Sealing—
The DODGE ProGuard™ Seal is a land-riding, positive contact seal with steel shield protection. The rubber seal lip is molded as an integral part of the steel shield. The highly effective land-riding design assures uniform lip contact with the ground O.D. of the inner ring. The nitrile rubber, especially compounded for minimum drag, provides full pillow block speed capabilities and outstanding wear characteristics. The steel shield is mechanically anchored into the bearing's outer ring to resist blowout.

Flingers—
Corrosion resistant flingers are mounted on each side of the bearing inner ring immediately adjacent to the seals and act as deflectors and seal protectors. The flingers form a tight labyrinth with the seal providing additional sealing, against ingress of water through the seal during pressure washdown and protection against contaminants and trash.

Shaft Mounting—
The inner ring is locked to the shaft by two setscrews spaced 65° apart. The 65° setscrew angle provides an optimum balance between shaft holding power and inner ring stress.

Lubrication—
The E-Z KLEEN Bearings with housings coated with *Teflon** are lubricated with NLGI No. 2 lithium-based grease. USDA- and FDA-accepted edible lubricant can be furnished as a made-to-order item for an additional charge.



*Patent Pending

Application:

DODGE E-Z KLEEN Bearings with housings coated with *Teflon** are suitable for meat processing and packing, dairy products, bottling, canning, vegetable and fruit processing, bakery and confection, cereal, seafood processing, frozen foods, and pharmaceutical and cosmetic industries.

Available Configurations:

E-Z KLEEN Bearings with housings coated with *Teflon** are stocked standard height pillow blocks, 4-bolt and 2-bolt flanges, and narrow slot take-up bearings. Other housing styles and take-up frames are available on a made-to-order basis.

Available Options:

- Corrosion resistant insert.
- F.D.A.-U.S.D.A. acceptable edible lubricant.
- Stainless steel screws for take-up frames.

These options can be furnished on a made-to-order basis for an additional charge. Contact DODGE for price and availability.

Nomenclature:

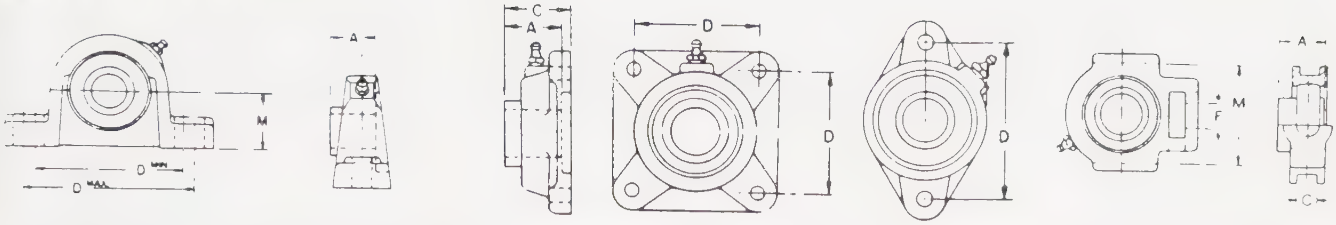
Each complete E-Z KLEEN Bearing with housings coated with *Teflo* is designated by a 6-digit part number. There is a separate 6-digit number for each size and configuration.

---

* Registered trademark of DuPont

DODGE®

Dimensions:*



Shaft Sizes	Other Shaft Sizes	A	C		D				F	M	
			Flanges	Take-Ups	Pillow Blocks		4-Bolt Flange	2-Bolt Flange		Pillow Blocks	Take-Ups
					Min.	Max.					
3/4	1/2 (204) + , 5/8 (204) +	1 5/32	1 23/64	1/4	3 3/8	4 3/16	2 1/2	3 17/32	3/4	1 5/16	2 5/8
1	7/8 + , 15/16 +	1 3/16	1 23/64	1/4	3 11/16	4 1/2	2 3/4	3 57/64	3/4	1 7/16	2 5/8
1 3/16	1 1/4 (206) 1 1/16 + , 1 1/8 +	1 25/64	1 17/32	1/4	4 1/4	5	3 1/4	4 19/32	3/4	1 5/8	3 1/2
1 3/16 SCUTC	1 1/4 (206) 1 1/16 + , 1 1/8 +	1 25/64	1 17/32	1/4	4 1/4	5	3 1/4	4 19/32	3/4	1 11/16	3 1/2
1 1/4 (207) 1 7/16	1 5/16 + , 1 3/8 +	1 17/32	1 27/32	1/4	4 11/16	5 7/16	3 5/8	5 1/8	3/4	1 7/8	3 1/2
1 1/2	1 5/8 (SC) + , 1 7/16 (SCM) +	1 11/16	1 7/8	5/16	5 3/16	5 7/8	4	5 21/32	7/8	2 1/8	4
1 15/16	1 11/16 (SCM) + 1 3/4 (SCM) +	1 3/4	2 1/32	5/16	6	6 11/16	4 3/8	6 3/16	7/8	2 1/4	4

+ Assemble to order

See Vol. 1 or Bulletin A-415-2 for all other dimensions

Features	Functions	Benefits
Housing Coated with *Teflon**	Protects housing in washdown environment	The coated housing resists oxidation, provides a "non-stick" surface for the food industry and is FDA approved.
DODGE ProGuard™ Seal	Retains lubricant and prevents contamination from external sources.	The positive contact land-riding seal is effective in washdown applications and resists blow-out. The low coefficient of friction of this contact seal reduces the torque required on start-up.
Corrosion Resistant Flinger	Protects seal and bearing from contaminants.	The flingers form a tight labyrinth with the seal, providing additional sealing against water, trash and contaminents.
65° Set Screw System	Locks the inner race of the bearing to the shaft.	The 65° angle offers improved holding power over 90° and 120° systems and reduces the stress on the inner ring as on the 45° system. In addition, this system offers ease of installation in cramped areas.
Anti-Rotation Pin	Locks the outer race of the bearing to the housing.	The pin provides the added insurance that the insert will not rotate in the housing due to unbalanced or eccentric loads.
Case Carburized Inner Ring	Provides internal rolling surface for bearing and contact surface from bearing to shaft.	Case hardened steel withstands surface wear on spherical race and absorbs shock loading in its inner core. Allows full use of bearing's load capacity and provides longer life. Resists inner ring cracking under heavy loads.

For More Information:

For more information about DODGE E-Z KLEEN Bearings with housings coated with *Teflon**, consult your DODGE/RELIANCE ELECTRIC Sales Representative.

Specify DODGE E-Z KLEEN®
Move faster with the leader.™

DODGE / P.O. Box 499 / 2 Ponders Court / Greenville, S.C. 29602-0499 / 803-297-4800 / FAX: 803-281-2318

RELIANCE ELECTRIC

© Reliance Electric Company, 1990

Circle 276

However, alloys with lead content over 20% are becoming difficult to obtain because they are difficult to cast.

Tin bronze: These alloys have high hardness, thus require reliable lubrication, good alignment, and a minimum Brinell shaft hardness of 300 to 400. They are used in high-load, low-speed applications such as trunnion bearings, gear bushings for off-road vehicles, rolling-mill bearings, and in internal combustion engines for connecting-rod bearings, valve guides, and starters.

Cast-bronze bearings offer good compatibility, casting, easy machining characteristics, low cost, good structural properties and high load capacity. They do not require a separate overlay or a steel backing.

Aluminum bronze: Bronzes of very high strength can be obtained by using aluminum, iron, manganese, silicon, and nickel as alloying elements. Such bearings have excellent shock and wear resistance. They retain high strength at high temperatures and are used in equipment operating above 500°F. A major use is in high-impact sliding surfaces in aircraft landing gear.

Because aluminum bronze has poor compatibility, embeddability, and conformability, it is best suited for heavy-duty, low-speed applications with plentiful lubrication. Aluminum bronzes require harder shafts than softer bearing materials. Proper alignment is more critical because of low conformability.

Beryllium copper: Adding about 1.8% by weight of beryllium and about 0.2% cobalt to copper provides an alloy with strength comparable to many steels. The high strength, hardness, and thermal conductivity of the alloy promotes its use in high load bearings, especially where reliability is required under occasional overload, impact, high temperature or marginal lubrication conditions. These alloys are used in electrically conducting applications and are frequently specified for aircraft landing gear and other airframe sliding surfaces.

Aluminum

Aluminum bearing alloys have wear resistance, high load-carrying capacity, fatigue strength, thermal conductivity, and excellent corrosion resistance and low cost. They are used extensively in connecting-rod and main bearings in internal combustion engines; in hydraulic gear pumps; in oil-well pumping equipment; in roll-neck bearings in steel mills; and in reciprocating compressors and aircraft equipment. Aluminum alloys require sufficient lubrication, good surface finish, and shafts hardened to about Rockwell B85. They have relatively poor compatibility characteristics, and lack embeddability and conformability. For automotive use, considerable improvement in antiscoring characteristics and embeddability is obtained by using a thin-lead babbitt or electrodeposited lead-tin overlay.

Aluminum bearing alloys are used either as solid cast material or as aluminum strips (normally from 0.020 to 0.125 in. thick) applied to steel backing. Cast alloys generally are specified by designations of The Aluminum Association, while the steel-backed bearings are usually specified by SAE designations.

An alloy widely used in crank and piston-rod bearings is a cast material, 850.0-T5 (equivalent to SAE 770). This alloy is the most ductile of the cast alloys and can withstand heavy loads without cracking or fretting. It also has good compatibility. An easier-casting version is A850.0-T5. In hardness, this alloy stands between the bronzes and the babbitts.

The most widely used cast aluminum-tin bearing alloy is B850.0-T5. Its properties are similar to those of general-purpose bronze. Alloy B850.0-T5 is the strongest of the aluminum alloys and can be used with moderate shock loads. But being harder, it does not conform to minor misalignments as readily as A850.0.

The most common steel-backed alloys are SAE 780 and 781. Alloy 780 is similar to SAE 770 (or 850.0-T5) except for having 1.5% more silicon. SAE 781 contains 1 to 3% cadmium for improved bearing properties. This alloy is used in making steel-back bearings with a 0.0005-in. overlay containing approximately 90% lead and 10% tin. The layer of babbitt improves surface properties during break-in.

A third type has been developed to provide steel-backed aluminum auto-

Properties of bronze and copper bearing alloys

Bearing type	Alloy	Designation	Nominal composition						Other	Hardness (Brinell)	Ultimate tensile strength (ksi)
			Cu	Sn	Pb	Al	Zn	Be			
Sintered*	Bronze	C90700	90	10	—	—	—	—	—	—	17
	Leaded bronze	C92500	85	10	3	—	—	—	—	—	—
	Iron bronze	NA	36	4	—	—	—	—	60 Fe	—	—
Laminated (Facing)	Copper-lead (Cast)	SAE 48	70	—	28	—	—	—	1.4 Ag	28	8
	Copper-lead (Sintered)	SAE 480	65	—	35	—	—	—	—	—	—
Laminated (Backing)	Med-lead. Tin-bronze	C93600	85	4	8	—	3	—	—	—	—
	High lead. Tin-bronze	C93800	78	6	15	—	—	—	—	48	25
Cast	Phosphor bronze	C93700	80	10	10	—	—	—	—	60	35
	Low lead. Tin-bronze	C92200	88	6	2	—	4	—	—	65	40
	Med. lead. Tin-bronze	C93200	83	7	7	—	3	—	—	65	35
	High lead. Tin-bronze	C93800	78	6	16	—	—	—	—	52	28
	Tin-bronze	C90300	68	8	—	—	4	—	—	68	40
	Aluminum bronze	C95400	65	—	—	11	—	—	4 Fe	195	90
Continuous cast	Phosphor bronze	C93700	80	10	10	—	—	—	—	80	41
	Low lead. Tin-bronze	C92200	88	6	2	—	4	—	—	65	40
	Med. lead. Tin-bronze	C93200	83	7	7	—	3	—	—	72	44
	High lead. Tin-bronze	C93800	78	6	16	—	—	—	—	62	34
	Tin-bronze	C90300	88	8	—	—	4	—	—	70	45
Roll formed (strip)	Commercial bronze	C22000	90	1	—	—	9	—	—	125	61
	Beryllium Copper	C17200	98	—	—	—	—	2	0.2CO	297	140
Forged or extruded	Aluminum nickel bronze	C63000	82	—	—	10	—	—	5Ni3Fe	228	118
(Rod. bar. tube)	Beryllium copper	C17200	98	—	—	—	—	2	0.2Co	352	165

*Sintered bearing strength and hardness are available over a wide range depending on the porosity level.

motive bearings with no need for a babbitt overlay. It is used in most English automobiles and diesel engines. Another class, which has been used in U.S. automobile engines, uses a dispersion of 5% lead in an 0.018-in.-thick aluminum overlay.

Other metals

Cadmium: Has high-temperature fatigue properties superior to those of babbitt. Cadmium has a low affinity for steel and excellent compatibility characteristics, so cadmium-base alloys are used in steel and bronze rolling mills for heavily loaded roll-neck bearings. Use of these alloys has dropped off, however, because of high cost and poor corrosion resistance.

Silver: These bearings are excellent for heavy-duty applications in aircraft engines and diesels. For reciprocating engines, silver bearings normally consist of electrodeposited silver on a steel backing, with an overlay of 0.001 to 0.005 in. of lead. The lead improves the embeddability and antiscoring properties of the silver. Indium is usually flashed on top of the lead overlay for corrosion protection.

The compatibility characteristics of silver can be used in other applications. A thin coating of silver plate frequently relieves any welding or seizing otherwise encountered under severe rubbing conditions in machine components.

Cast iron and steel: These materials are used in inexpensive bearings for operation under relatively light loads. Flake graphite in the cast iron develops a glazed surface which is useful at surface speeds up to 130 fpm and at loads up to about 150 psi. Frequently, the bearing surface is machined directly in a cast iron structure. Because of the poor conformability of cast iron, good alignment and cleanliness are essential. Guide bushings and lightly loaded journal bearings can also be machined directly in steel structural parts for loads up to 200 psi for operation at speeds up to 150 fpm.

Porous metals

Most porous-metal bearings consist of either bronze or iron which has interconnecting pores. These voids take up to 10 to 35% of the total volume. In operation, lubricating oil is stored in these voids and feeds through the interconnected pores to the bearing surface. Any oil which is forced from the loaded zone of the bearing is reabsorbed by capillary action. Because these bearings can operate for long periods without additional lubricant, they can be used in inaccessible or inconvenient places where relubrication would be difficult.

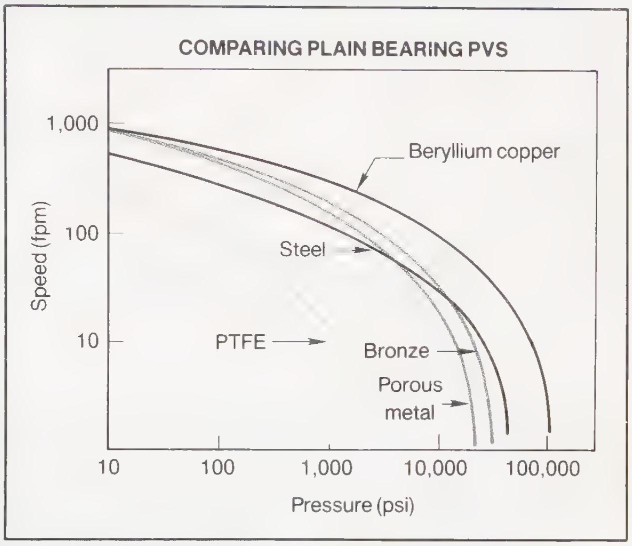
From 1 to 3.5% graphite is frequently added to enhance self-lubricating properties. High porosity with a maximum amount of lubricating oil is used for high-speed light-load applications, such as fractional-horsepower motor bearings. A low-oil-content low-porosity material with a high graphite content is more satisfactory for oscillating and reciprocating motions where it is hard to build up an oil film.

Powder producers can control powder characteristics such as purity, hydrogen loss, particle size and distribution, and particle shape. Each of these properties in some ways affects performance. In the bronze system, for example, shrinkage increases as particle size of tin or copper powder in the mix decreases. Graphite additions result in growth but always lower the strength of

PV FACTORS FOR POROUS METAL BEARINGS

Limiting conditions for operation of porous bearings can be expressed as *PV* factor. Since *P* = load, psi; and *V* = surface velocity, fpm; the *PV* value gives an index of frictional heat generated on a unit area of the bearing surface. A maximum value of 50,000 is common for porous bearings. For longtime running with no additional lubrication, 20,000 should be a limit in selecting loads for various speeds. For thrust bearings, a maximum *PV* of 10,000 should be used.

Provision to replenish the oil supply is desirable when the *PV* factor approaches the maximum under continuous operation for extended periods of time, or for high temperatures. For such cases, oil can be applied to the OD or ends of the bearing. From there it is drawn, by capillary action, into the bearing and metered to the shaft. A reservoir of grease next to the bearing also can be helpful.


COMPARING PLAIN BEARING PVS

Material	*PV*	Static *P* (psi)	Dynamic *P* (psi)	*V* (fpm)
Bronze	50,000	8,000	2,000	1,200
Lead-bronze	60,000	3,500	800	1,500
Copper-iron	35,000	20,000	4,000	225
Hardenable copper-iron	75,000	50,000	8,000	35
Iron	30,000	10,000	3,000	400
Bronze-iron	35,000	10,500	2,500	800
Lead-iron	50,000	4,000	1,000	800
Aluminum	50,000	4,000	2,000	1,200

Under certain conditions these recommended values can be exceeded but with a sacrifice in service life

Yield strength (ksi)	Maximum operating Temp. (F)	Maximum bearing Pressure (ksi)
16	—	2
—	—	—
—	—	2
—	350	2
—	—	—
—	—	—
12	400+	3
18	450+	4
20	450+	4+
18	450+	4
14	450	3+
18	500	4+
40	500+	4.5+
26	450+	4
20	450+	4
27	450+	4
23	450	3+
21	450+	4
75	500+	7
115	500+	10+
75	500+	8
140	500+	10+

the bearings. Lubricants used in the mix have only a slight influence on dimensional change, but a more pronounced effect on the apparent density and flow rate.

After sintering, the bearing must be sized to the specified dimensions. Sizing reduces interconnected porosity and produces greater strength, lower ductility, and a smoother finish.

Bronze: The most common porous bearing material. It contains 90% copper and 10% tin. These bearings are wear resistant, ductile, conformable, and corrosion resistant. Their lubricity, embeddability, and low cost give them a wide range of applications from home appliances to farm machinery.

Leaded bronzes: Have a 20% reduction of the tin content of the usual 90-10 bronze and 4% reduction in copper. Lead content is 14 to 16% of total composition and results in a lower coefficient of friction and good resistance to galling in case the lubricant supply is interrupted. These alloys also have higher conformability than the 90-10 bronzes.

Copper iron: The inclusion of iron in the composition boosts compressive strength although the speed limit drops accordingly. These materials are useful in applications involving shock and heavy loads, and should be used with hardened shafts.

Hardenable copper iron: The addition of 1½% free carbon to copper-iron materials allows them to be heat treated to a particle hardness of Rockwell C65. They provide high impact resistance and should be used with hardened-and-ground shafts.

Iron: Combine low cost with good bearing qualities, widely used in automotive applications, toys, farm equipment, and machine tools. Powdered iron is frequently blended with up to 10% copper for improved strength. These materials have a relatively low limiting value of *PV* (on the *V* side), but have high oil-volume capacity because of high porosity. They have good resistance to wear, but should be used with hardened-and-ground steel shafts.

Leaded iron: Provide improved speed capability, but are still low-cost bearing materials.

Aluminum: In some applications they provide cooler operation, greater tolerance for misalignment, lower weight, and longer oil life than porous bronze or iron. The limiting *PV* value is 50,000, the same as for porous bronze and porous iron.

Plastics

Although many different types of plastics have properties which make them suitable for bearing applications, the most commonly used are phenolics, acetals, UHMWPE, and nylon. The major limitations involved in the use of plastics have to do with high temperatures and possible cold flow under heavy loads.

Phenolics: Composite materials that consist of cotton fabric, asbestos, or other fillers bonded with phenolic resin. The compatibility of the phenolics makes them easily lubricated by various fluids.

They have replaced wood bearings and metals in such applications as propeller and rubber-shaft bearings in ships, and electrical switch-gear, rolling-mill, and water-turbine bearings. In small instruments and clock motors, laminated phenolics serve as structural members as well as a bearing material. They have excellent strength and shock resistance, coupled with resistance to water, acid, and alkali solutions.

Some precautions must be observed with phenolic bearings. Thermal conductivity is low, so heat generated by bearing friction cannot be readily transmitted through the bearing liner. Consequently, larger, heavily loaded bearings must have a generous feed of water or lubricating oil to carry away heat. Some swelling and warping of these bearings occurs in the larger sizes, so larger-than-normal shaft clearances are required.

Nylon: Although the phenolics have

DESIGNING WITH NONMETALLIC BEARINGS

The *PV* factor, used as a load-speed limit, provides a basis for estimating relative wear rates. The total volume of material worn away is approximately proportional to the total normal load multiplied by the distance traveled in a length of time. Thus, $R = K(PV)T$, where R = radial wear in a sleeve bearing, in.; K = wear factor in.^{3}-min/ft-lb-h; P = load, psi; V = surface velocity, fpm; T = time, h.

This equation does not always provide accurate absolute values for wear rate, but it is useful for estimating relative wear rates for alternative materials. In general, K wear values with fillers are lower than for unfilled materials. If wear values are important for specific components, life tests should be made. These might employ moderately accelerated load and speed condition to obtain a K value representative of the plastic, the shaft and its finish, and the application conditions.

	Load capacity (psi)	Max Temp (°F)	Max Speed (fpm)	*PV* Limit (Unlubricated)
Phenolics	6,000	200	2,500	15,000
Nylon	2,000	200	600	3,000
PTFE	500	500	50	1,000
Filled PTFE	2,500	500	1,000	10,000
PTFE fabric	60,000	500	150	25,000
Poly-carbonate	1,000	220	1,000	3,000
Acetal	2,000	200	600	3,000
Carbon-graphite	600	750	2,500	15,000
Rubber	50	150	4,000	—
Wood	2,000	160	2,000	12,000

K values should be increased by 50% for cast iron and bronze shafts, and more than 5 times with soft stainless-steel or aluminum alloys. Increased surface hardness can markedly reduce wear, while surface roughness of the shaft often has an optimum value in the 4-12 μin. rms range. Lubrication also has a pronounced influence on wear. With oil impregnation, wear rates commonly drop to negligible values with plastics, wood, and porous metals.

	Wear factor K (in.^{3}=min/ft-lb-h) Filled*	Wear factor K (in.^{3}=min/ft-lb-h) No filler
Nylon	16×10^{-10}	200×10^{-10}
Polyester	$20 \times 10^{\ 10}$	—
Polycarbonate	30×10^{-10}	$2{,}500 \times 10^{-10}$
Polyurethane	35×10^{-10}	—
Polypropylene	36×10^{-10}	—
Styrene acrylonitrile	$65 \times 10^{\ 10}$	—
Polysulfone	70×10^{-10}	—
Acetal	200×10^{-10}	$65 \times 10^{\ 10}$

For 40 psi load at 2,000 *PV* operating against carbon steel of hardness 20 Rc with a 6-12 microin finish.

*Filled with 30% (by weight) glass fiber 15% (by weight) PTFE.

Bearings, Inc.
Bruening · Dixie · King

BEARINGS

Circle 277

BEARINGS, INC., YOUR BEST SOURCE FOR BALL, ROLLER, THRUST, MOUNTED & PLANE BEARINGS

Anti-friction Bearings

As the leading bearings distributor, Bearings, Inc. carries the largest stock of the most popular anti-friction bearings in the United States. We carry an extensive range of bearings made from today's most popular and responsive bearing materials. We can meet your specific needs with bearings engineered to fit a wide span of designs, environments, and applications. Bearings, Inc. is the authorized distributor for more than 30 major brands – the top quality brands you trust. Our service never stops at the sale, our trained specialists are available to provide technical and application support twenty-four hours a day. Whether you need ball, spherical, cylindrical, mounted, tapered, cam or linear bearings, Bearings, Inc. is your one-stop source of anti-friction bearings.

Anti-friction Bearing Brands

Bearings, Inc. carries a wide selection of the following brands of anti-friction bearings:

Aetna • Alinabal • American • Andrews (INA) • Auburn (NOLU) • BCA • B&RB • Barden • Cooper • Dodge • Fafnir/Torrington • FAG • GMN • Heim • INA • Kaydon • Kilian • MB Mfg. • Messinger • McGill • MPB • MRC Div. of SKF • New Hampshire • Nice • NOLU • Osborn • Link-Belt/Rexnord • RBC • Rexnord • RMB • Rollway • Rotek • Royersford • Sealmaster • SKF • SKF-Tyson • Split Ball Bearing • Stearns-Stafford • Thomson • Timken • Torrington/Fafnir

BALL BEARINGS

SPHERICAL/CYLINDRICAL BEARINGS

MOUNTED BEARINGS

TAPERED BEARINGS

Bearings, Inc.
Bruening • Dixie • King

Plane Bearings

Bearings, Inc. offers a full range of fabricated metallic and non-metallic plane bearings. Each have outstanding physical properties while giving you high performance and low noise. Our metallic plane bearing stocks include: SAE 660 bronze bearings in bars, plates and tubes; electric motor bearings; U.S. Government Babbitt; sintered oil impregnated bearings; powdered metal bearings in bars and plates; tempered steel bearings; rolled strip bronze bearings and many other types of bronze bearings. Our non-metallic plane bearing stocks include: PTFE bearings in rods, tubes, sheets & shapes; PTFE composites in nylon rods, tubes, sheets and shapes; impregnated plastics; metal and plastic composites; UHMW composites; water lubricated bearings and wood bearings.

CAM BEARINGS

LINEAR BEARINGS

PLANE BEARINGS

Plane Bearing Brands

Our trained specialists are available to assist you with your plane bearing needs; ensuring the proper material and grooving for maximum efficiency in your application. Bearings, Inc. carries a wide selection of the following manufacturer's brands:

Western Reserve Bronze - Microcast™ • MagnaCast™ - Aluminum Bronze • SYMMCO • Stripmatic Products • ERMCO-MAXAM® • Norton Performance Plastics • The Polymer Corporation • The Wheeler Group - Electric Motor Bearings • Garlock Bearings - DU®, DX®, GAR-FIL®/GAR-MAX®, & MULTIFILL® • THOMSON Nyliner® • Pacific Bearing Co.- Simplicity™ Bearings • Solidur Plastics • NOLU® Plastics • Dixon Industries Group - Rulon® LD, Dixon CJ and Dixon CW • BF Goodrich - Cutlass® & Commander® Bearings • WOODEX Bearings - Impregnated Wood & Lignum Vite Bearings

Additionally, we represent many other plane bearing manufacturers including:

Arguto • Bushings, Inc. • Fiberglide® Bearings • Morse Marine Bearings • Dodge • Government Genuine Babbitt • Graphalloy • PTC/Link-Belt • Randall • Spadone-Alfa "Metaline"

Circle 277

Bearings, Inc.
Bruening • Dixie • King

OVER 330 STOCKING BRANCHES TO SERVE YOU

BEARINGS, INC. CONNECTICUT • DELAWARE • IDAHO • INDIANA • MAINE • MARYLAND • MASSACHUSETTS • MONTANA • NEW HAMPSHIRE • NEW JERSEY • OHIO • OKLAHOMA • OREGON • PENNSYLVANIA • RHODE ISLAND • VERMONT • WASHINGTON • WEST VIRGINIA

BRUENING BEARINGS, INC. ILLINOIS • KENTUCKY • MISSOURI • NEW YORK

DIXIE BEARINGS, INC. ALABAMA • ARKANSAS • FLORIDA • GEORGIA • LOUISIANA • MISSISSIPPI • NORTH CAROLINA • SOUTH CAROLINA • TENNESSEE • VIRGINIA

KING BEARING, INC. ARIZONA • CALIFORNIA • NEVADA • NEW MEXICO

BEARINGS, INC. KING BEARING DIVISION TEXAS

FOR OUR COMPLETE PRODUCT CATALOG
CALL 1-800-322-3460

Certain anti-friction and plane bearing brands are not sold at all locations.
Please consult with your local branch for availability.

3600 Euclid Avenue • Cleveland, Ohio 44115 • Phone (216) 881-8900 • FAX (216) 881-8988

© 1992 Bearings, Inc.
All Rights Reserved.
C-406-3661-C

Circle 277

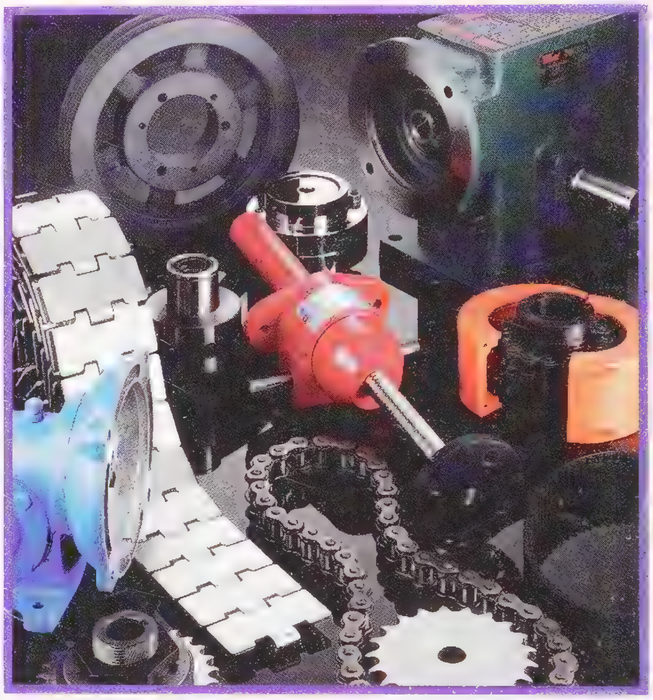
Bearings, Inc.
Brunning • Dixie • King

MECHANICAL POWER TRANSMISSION

BEARINGS, INC., YOUR BEST SOURCE FOR COUPLINGS, DRIVE & CONVEYING COMPONENTS, MECHANICAL ADJUSTABLE SPEED DRIVES AND CLUTCHES & BRAKES

POWER TRANSMISSION

From the power source to the work unit, power transmission components work to keep your machinery operating smoothly. Bearings, Inc. offers a complete line of standard and custom power transmission components - gears; clutches & brakes; gear & fluid couplings; all steel, stainless steel & nylon sprockets; adjustable speed drives; Taper-Lock® & QD bushings; sheaves; and troughing & flat idlers. We also stock timing & V-belts; chain tensioners; head & tail pulleys; roller, table-top, conveying, & welded steel chains - plus more. All to provide you with the parts you need when you need them. With more than 75 well-known and trusted power transmission brand names and trained, experienced power transmission specialists to stand by our lines, Bearings, Inc. is your one-stop source.



Power Transmission Brands

Bearings, Inc. carries a wide selection of the following manufacturer's brands:

DRIVE COMPONENTS

Belts

Brammer • Dodge • Gates • Goodyear • Manheim • Morse • PIC • Winfred Berg

Gears

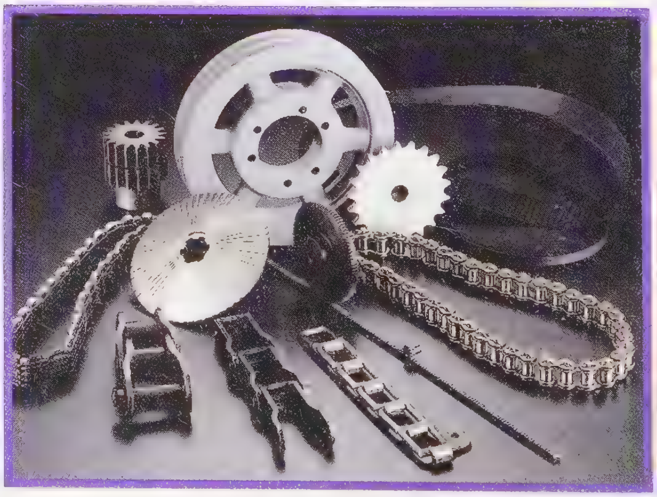
Globe • Martin • PIC • Skidmore • Winfred Berg

Roller Chain/Timing Belt Sprockets

Brewer • Dalton • Dodge • H. Neuman • Linn • Martin • Morse • Murray • PIC • Rexnord/Link-Belt • Ryle • Winfred Berg

Sheaves

Brewer • Congress • Dodge • Electron • Martin • Morse • TB Woods



Bearings, Inc.
Brunning • Dixie • King

COUPLINGS

Deck • Dodge • Falk • Gerbing • Globe • Kop-Flex • K-Power • Lovejoy • Martin • Magnalloy • Morse • Johnson Power • PIC • Poole • Rexnord/Link-Belt • Sier Bath • Spicer • TB Woods • Waldron • Winfred Berg • Zurn

CONVEYING COMPONENTS

B&B • Dodge • FMC/Material Handling • Moline • Precision Pulley • Rexnord/Link-Belt • Stephens-Adamson • Union Chain • Valu Guide • Van Gorp • Webster Ind.

CLUTCHES/BRAKES

Dodge • Dynacorp • Horton • Morse • Stearns

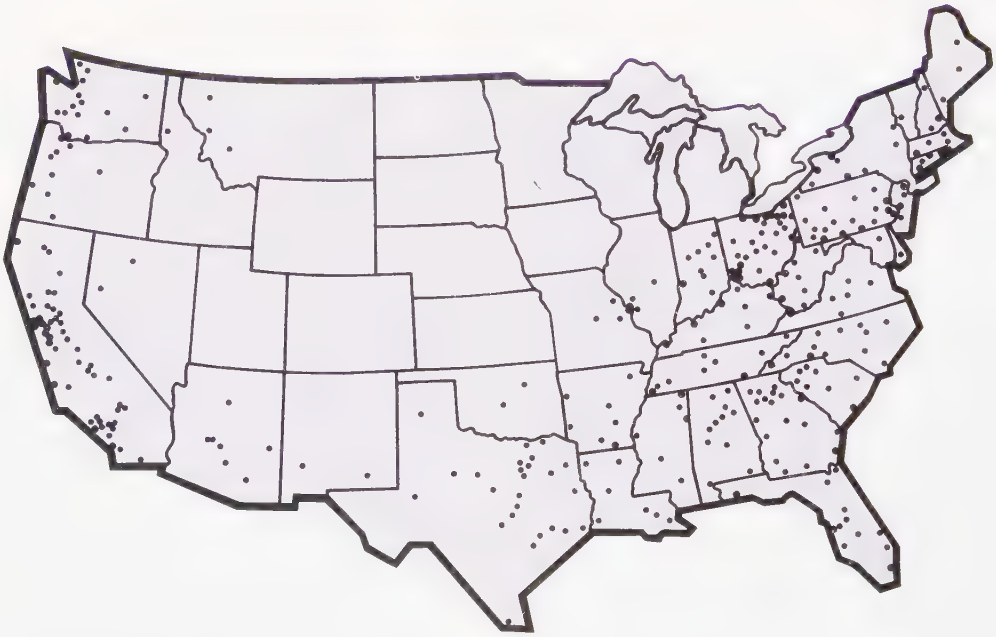
SPEED REDUCERS AND ADJUSTABLE SPEED DRIVES

Dodge • Falk • Grant Gear • Hub City • Leroy Somer • Morse • Reliance-Reeves • Rexnord/Link-Belt • Speed Selector • US • Winsmith

Circle 680

Bearings, Inc.
Bruening • Dixie • King

OVER 330 STOCKING BRANCHES TO SERVE YOU



BEARINGS, INC. CONNECTICUT • DELAWARE • IDAHO • INDIANA • MAINE • MARYLAND • MASSACHUSETTS • MONTANA • NEW HAMPSHIRE • NEW JERSEY • OHIO • OKLAHOMA • OREGON • PENNSYLVANIA • RHODE ISLAND • VERMONT • WASHINGTON • WEST VIRGINIA

BRUENING BEARINGS, INC. ILLINOIS • KENTUCKY • MISSOURI • NEW YORK

DIXIE BEARINGS, INC. ALABAMA • ARKANSAS • FLORIDA • GEORGIA • LOUISIANA • MISSISSIPPI • NORTH CAROLINA • SOUTH CAROLINA • TENNESSEE • VIRGINIA

KING BEARING, INC. ARIZONA • CALIFORNIA • NEVADA • NEW MEXICO

BEARINGS, INC. KING BEARING DIVISION TEXAS

FOR OUR COMPLETE PRODUCT CATALOG
CALL 1-800-322-3460

Certain brands of mechanical power transmission products are not sold at all locations.
Please consult with your local branch for availability.

3600 Euclid Avenue • Cleveland, Ohio 44115 • Phone (216) 881-8900 • FAX (216) 881-8988

© 1992 Bearings, Inc.
All Rights Reserved.
C-406-3662-C

Circle 680

predominated in heavy-duty applications, they are frequently replaced by nylon, which has the widest use in bearings. Nylon bushings exhibit low friction and require no lubrication. Nylon is quiet in operation, resists abrasion, wears at a low rate, and is easily molded, cast, or machined to close tolerances. Possible problems with cold flow at high loads can be minimized by using a thin liner of the material in a well-supported metal sleeve.

Improvement in mechanical properties, rigidity, and wear resistance is obtained by adding fillers such as graphite and molybdenum disulfide to nylon. While the maximum recommended continuous service temperature for ordinary nylon is 170°F, and 250°F for heat-stabilized compositions, filled-nylon parts resist distortion at temperatures up to 300°F.

PTFE: Has an exceptionally low coeffecient of friction and high self-lubricating characteristics, immunity to almost all types of chemical attack, and ability to operate over extremely wide temperature range (−330 to 360°F continuous; 550°F short-term).

New reinforcing constructions, particularly tin bronze and stainless steel interlayer reinforcement (metal fabric), have raised PV ratings, minimized cold flow, and extended wear life substantially. These have outperformed properly applied metal sleeve bearings at PVs of 30,000 or more. Other reinforcing constructions include fabric, powder metal filler, and steel backing in various combinations.

Cost of PTFE bearing material is high relative to plain metal or other resins. But, applications for PTFE center in low rpm, oscillatory or intermittent service or where reliable service without lubrication is vital. Load capacity depends on construction and reinforcing material. Many applications include exposure to weather, chemicals, or vapors which attack metals, lubricants, and some plastics. Others, such as sluice gates, involve the need to operate smoothly, reliably, and without sticking after prolonged idle periods.

Successful applications have included pedal mechanisms, linear actuators, process valve stems, trunnions, pivots, reciprocating mechanisms, automotive knuckle and ball joint, office equipment, healthcare equipment, production equipment, farm machinery, textile machinery, and aircraft accesories. An important application (for unfilled types) is in food and packaging machinery where FDA regulations prohibit most lubricants for sanitary reasons.

Since lubricant clearances are not needed, metal fabric reinforced PTFE bearings are used increasingly to improve stiffness and reduce bearing play in a mechanism. Interference fits are even possible; the metal fabric keeps the PTFE in place. Generally, higher loads are possible at lower speeds.

PTFE reinforced with tin bronze fabric exhibits particularly long wear life a high load because interlayer reinforcing fabric is itself a bearing material. Applications and tests have involved static loads to 50,000 psi and dynamic loads of 35,000 psi at moderately low rpms. The bearing still functions and friction coefficient remains low even when worn to the point where bronze fabric is exposed. The shaft rides mainly on PTFE lodged in pockets of the fabric and contact of the shaft with bronze in the fabric is acceptable; an equilibrium of sorts results. The reinforcing metal fabric also helps dissipate heat. In extremely corrosive applications, stainless steel fabric adds protection against unwanted chemical reactions if wear exposes the metal.

In metal fabric-type reinforcements, mechanical interlock between PTFE and fabric has the advantage of holding the PTFE in place and reducing cold flow, resulting in prolonged life. Metal and glass fabrics create a more economical, more supple bearing material. Metal fabrics add substantial strength, dimensional stability, wear life, and heat dissipation. Fabric-reinforced PTFE is readily handled and applied, and is adequate for many moderate-PV applications such as automotive thrust washers, ball and socket joints, aircraft controls and accessories, bridge bearings, and electrical switch gear. To provide a strong bond to steel or other rigid backing material, a secondary fiber such as polyester, cotton, or glass is commonly interwoven with the PTFE and then bonded to the backing.

Improved versions have woven or braided "socks" (of PTFE and bondable material). The bearing sleeve is then filament wound with a fiberglass epoxy shell. These bearings may carry static loads up to 50,000 psi. Another bearing material combines low friction and good wear resistance of filled PTFE with strength and thermal conductivity of bronze and steel-supporting structure. A plated steel backing is covered with a thin layer of sintered spherical bronze particles. The porous bronze is impregnated with a mixture of PTFE and lead to provide a thin surface layer. Service temperatures of −330 to 536°F are possible. For higher loads and PVs, stainless-steel fabric reinforced PTFE bonded to a steel backing provides durability and low friction.

A self-lubricating material employs a proprietary bonding process that allows a filament-wound PTFE liner to be fabricated without a secondary bondable fiber. This places more PTFE at the wear surface. In addition, the material includes a support backing of filament-wound fiberglass which is epoxy bonded. This filament-wound material can carry static loads to 25,000 psi.

Design approach is similar to plain metal bearings except for lubrication provisions. As a class, PTFE bearing materials are a little more forgiving of rough mating surfaces, tolerances, and misalignments than plain metal bearings. For dynamic applications, smoothness of the mating surface should be 32RMS or better. Out of roundness for shaft or hole should not exceed half the diameter tolerance. Although not essential, a one-time initial lubrication application, where permitted, will prolong life and enhance performance.

Acetal: Has been used for inexpensive bearings in a wide variety of automotive, appliance, and industrial applications. It is particularly useful in wet environments because of its stability and resistance to wet abrasion.

Polyimide, polysulfone, polyphenylene sulfide: High-temperature materials with excellent resistance to both chemical attack and burning. With suitable fillers, these moldable plastics are useful for *PV* factors to 20,000 to 30,000. Polyimide molding compounds employing graphite as a self-lubricating filler show promise in bearing, seal, and piston ring applications at temperatures to 500°F. Polyphenylene sulfide can be applied as a coating through use of a slurry spray, dry powder, or fluidized bed. These coating techniques require a final bake at about 700°F.

Ultrahigh-molecular-weight polyethylene: Resists abrasion and has a smooth, low-friction surface. Often an ideal material for parts commonly made from acetal, nylon, or PTFE materials.

Other nonmetallics

Nonmetallic materials offer self-lubricating properties, high-temperature stability, solvent resistance, or low cost. The most common of these are carbon graphite, wood, rubber, and ceramics.

Carbon graphite: The self-lubricating properties of carbon bearings, their stability at temperatures up to 750°F, and their resistance to attack by chemicals and solvents, give them important advantages where other bearing materials are unsatisfactory. Carbon-graphite bearings are used where contamination by oil or grease is undesirable, as in textile machinery, food-handling machinery, and pharmaceutical processing equipment. They are used as bearings in and around ovens, furnaces, boilers, and jet engines where temperatures are too high for conventional lubricants. They are also used with low-viscosity and corrosive liquids in such applications as metering devices or pumps for gasoline, kerosene, water, seawater, chemical process streams, acids, alkalis, and solvents.

RING JEWELS AND ENDSTONES

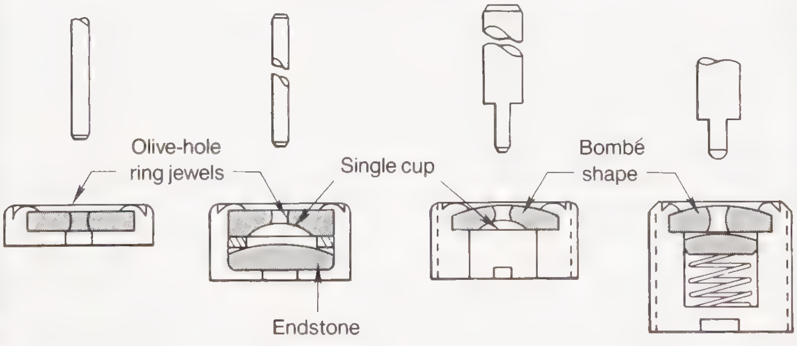
Jewel bearings are best applied where torque, load, and speed are low as in gages and instruments.

Jewel bearing are usually used where a rotating shaft is circular, requiring an annular bearing. Also, the pivot or shaft may extend through the bearing to support a portion of the instrument outboard of the bearing. Jewel bearings are also good electrical insulators. Other jewel bearing features are:

Concentricities normally within 0.0002 in. When mounted in a housing, normal concentricity is 0.0005 in TIR. Additional truing can improve this figure to 0.0003 in. and reduce it to 0.0001 in. if required. However, increased concentricity adds cost to the bearing.

Tolerances to the ID of a bearing are normally ±0.0002 in., up to about 0.08-in. ID. For larger IDs, ±0.0003 in. is common for economical production.

TYPICAL JEWEL BEARING ASSEMBLIES



The composition and processing used with carbon bearings can be varied to provide characteristics required for particular applications. Carbon graphite has from 5 to 20% porosity. These pores can be filled with a phenolic or epoxy resin for improved strength and hardness, or with oil or metals (such as silver, copper, bronze, cadmium, or babbitt) to improve compatibility properties.

A *PV* limit of 15,000 ordinarily can be used for dry operation of carbon bearings. This should be reduced for continuous running with a steady load over a long period of time to avoid excessive wear. When operating with liquids which permit the development of a supporting fluid film, much higher *PV* values can be used.

A hard, rust-resistant shaft with at least a 10-μin. finish should be used. Hardened tool steel or chrome plate is recommended for heavy loads and high-speed applications. Steel having a hardness over Rockwell C50, bronzes, 18-8 stainless steels, and various carbides and ceramics also can be used.

Certain precautions should be observed in applying carbon graphite. Since this material is brittle, it is chipped or cracked easily if struck on an edge or a corner, or if subjected to high thermal, tensile, or bending stresses. Edges should be relieved with a chamfer. Sharp corners, thin sections, keyways, and blind holes should be avoided wherever possible. Because of brittleness and low coefficient or expansion (about one-fourth that of steel), carbon-graphite bearings are often shrunk into a steel sleeve. This minimizes changes in shaft clearance with temperature variations and provides mechanical support for the carbon-graphite elements.

Rubber: Elastomeric materials give excellent performance in bearings on propeller shafts and rudders of ships, and in other industrial equipment handling water or slurries. The resilience of rubber helps isolate vibration to provide quiet operation, allows running with relatively large clearances, and helps compensate for misalignment.

Commercial rubber bearings consist of a fluted structure supported in a solid metal shell. This allows the shaft to be carried on a series of rubber strips running the length of the bearing. A water flow 2 gpm/in. of diameter is normally provided to cool the bearing and to flush through any dirt collecting in the channels between the rubber strips. Maximum load should be limited to 35 to 50 psi. There is no limit on speed, as long as operating temperature remains below 150°F.

Wood: Lignum vitae and oil-impregnated maple and oak offer self-lubricating properties, low cost, and clean operation. Wood bearings are useful at temperatures up to 150°F and at speeds up to several hundred rpm.

Ceramics: Silicon nitride has been developed as a high performance bearing material exhibiting fatigue properties equaling or exceeding that of high quality bearing steels. The primary use for these materials is in such rolling elements as balls and rollers for integration in bearings made with steel races. Such bearings are hybrid ceramic and are available in most sizes with standard offerings available in high performance super precision ball bearings. All-ceramic bearings are available in limited quantities upon special order for special applications.

The hardness, rigidity, corrosion resistance, and fine finish of various ceramics, carbides, and cermets have made them of great interest as bearing materials. Except for silicon nitride, there is only limited success in applying these materials as bearings.

Sapphire and glass: Synthetic industrial sapphire (100% aluminum oxide) is widely used for jewel bearings in low-torque instrument applications. Borosilicate glass has been substituted for sapphire in some applications. Jewel bearings are available in several configurations, including vee, ring, endstones, cup, and orifice.

Plain bearings

A plain bearing works by sliding action. This group encompasses most types other than rolling-element bearings. They are often referred to as "sleeve" or "thrust bearings," terms that designate whether the bearing is loaded radially or axially.

Lubrication is important, so their application and function is also often referred to according to the type of lubrication principle used. Thus, terms

INA Housing Units Solve Your Toughest Application Demands

INA's new North American-made cast iron housings feature a slick, cleanable surface that makes other units appear unfinished. These durable, one-piece housings also include thicker flanges for added strength, plus tight housing bore tolerances for consistent fit and interchangeability of the insert bearings mounted within them.

Choose from standard pillow blocks and two- or four-bolt flanges sized for a full range of inch and metric shaft diameters. Then, complete your INA assembly with the precise insert bearing you need with set screw or locking collar options.

For more information, contact INA Bearing Company, Inc., 308 Springhill Farm Road, Fort Mill, SC 29715, phone (803) 548-8500.

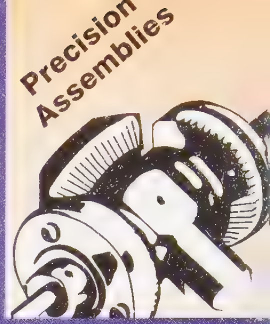
Circle 278

NORTH AMERICAN-MADE

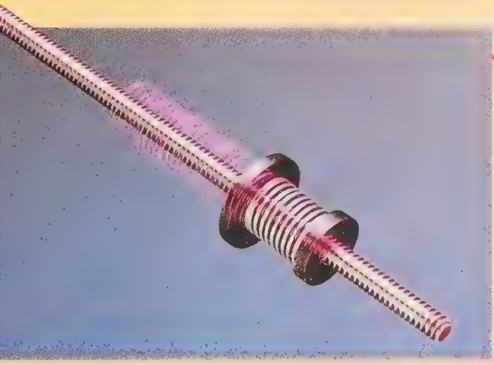
Add your custom color and name imprint.

INA Bearing Company, Inc.

BERG *Product News*



The following information highlights a selection of the comprehensive range
Precision Assemblies available in the Berg Manual. Send for your **Free Copy**



Lead Screw Assembly

Tech Data
- 1/8", 3/16" and 1/4" Shafts Avail.
- .0337 and .0500 Lead/ Rev.
- 4-5/16" Total Travel

Features
- Stainless Steel and Alum. Components
- Available with Ball or Bronze Bearings
- 24 Combinations to Choose From

Speed Reducers

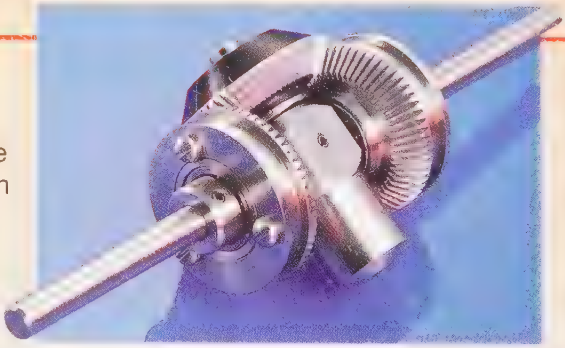
Tech Data
- #10, #11 and #18 Housing Size
- ABEC - 5 Bearings
- Maximum Backlash 30"
- 9:1 to 3600:1 Ratios Available
- 1/8" & 1/4" Shaft Sizes

Features
- Alum Housing and Steel Components
- Quiet Operation
- Over 50 Ratios Av
- 75 Stock Items

Differentials

Tech Data
- 5/64" to 1/4" Shafts Avail.
- Maximun Torque 50 oz. in.
- Maximum Speed 3000 RPM

Features
- Stainless Steel and Aluminum
- 10 Sizes Available
- Smooth Operation



Miter & Bevel Gear Boxes

Tech Data
- 1/8", 3/16" and 1/4" Shafts Avail.
- Maximum Torque 500 oz. in.
- 1:1, 1:2 and 1:3 Ratios Avail.
- Maximum Backlash 10'
- Maximum Speed 2500 RPM

Features
- St.. Steel, Molded Acetal Homopolymer and/or Alum. Components
- Available with Ball or Bronze Bearing
- 15 Sizes Avail.
- Commercial Line Avail.

Geneva Mechanisms

Tech Data
- 90°, 72°, 60° and 45° Single Cam Intermittent Motion
- 45°, 36°, 30°, ans 22.5° Double Cam Intermittent Motion
- 1/4" Bore Size
- Max Speed - 300 RPM

Features
- St. Steel and Alum. Components
- Bi-Directional
- Replacement Cam Followers Available

Servo Gear Boxes

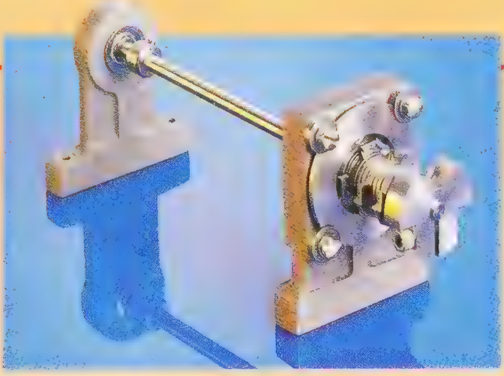
atures

Stainless Steel
and Aluminum
Available With Internal
Slip Clutch
Avail. with Geneva
(Intermittent Motion)
41 Ratios Available
Available with Anti-backlash
Gear in Output

Tech Data
- Torque Range to 600 oz. in.
- Max Backlash 15' On Ball Bearing Unit and 30' on Bronze Bearing Unit
- Maximum Speed 5000 RPM
- 2:1 to 625:1 Ratios Available
- 1/8", 3/16" and 1/4" Shafts Available
- Same and Opposite Shaft Rotation Avail.

Limit Stop Assembly

Tech Data
- Maximum Torque 500 oz. in.
- Starting Torque from .03 in. oz.
- Max. Rotation (0° - 4530° On Lug Style) (0° - 14400° On Miniature Housing Version)

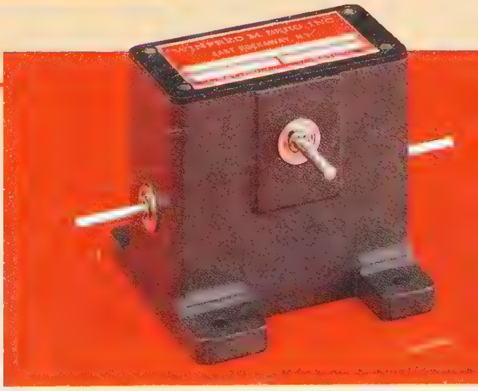


Features
- Stainless Steel and Alum. Components
- Hanger and Housing Versions Avail.
- Adjustable Limits
- 33 Stock Units

Wormwheel & Helical Gear Boxes

Tech Data
- 1/8", 3/16" and 1/4" Shaft Sizes
- Maximum Torque 500 oz. in.
- 1:1 to 120:1 Ratios Avail.
- Max. Backlash 20' on Ball Bearing Units and 30' on Bronze Bearing Units
- Maximum Speed 2000 RPM

Features
- Stainless Steel, Bronze and/or Alum. Components
- Available with Ball or Bronze Bearings
- 18 Ratios Available
- 172 Stock Items



BERG

Winfred M. Berg Inc., 499 Ocean Avenue, East Rockaway, New York 11518

Sales/Customer Service (516)559-5010, Gen. Tel. (516)596-1700, Fax (516)599-3274, Telex 9103506176

Circle 279

FILAMENT-WOUND BEARINGS

Filament-wound composite bearings are used in control and hinge-pin linkages that operate with oscillating motion under both high loads and low speeds. These bearings have filled-PTFE liners that eliminate the need for oil lubrication. The life of these bearings depends on such factors as load, oscillating angle, cycle rate, shaft material, shaft surface finish, and shaft hardness.

The effect shaft characteristics (such as surface finish or hardness) have on bearing life is frequently neglected. Consequently, short life for filament-wound bearings often can be traced to improper shaft selection.

For instance, conventional carbon-steel shaft materials — used with oil-lubricated metal plain bearings — may not be adequate for a nonlubricated filament-wound bearing. Small-angle oscillation or small-amplitude vibration can generate fretting corrosion at the shaft surface. The wear debris from fretting that accumulates between mating surfaces acts as an abrasive that drastically shortens bearing life. The use of corrosion-resistant materials such as series 300 or 400 stainless steels can eliminate such fretting corrosion problems and can improve bearing life significantly.

The life of filament-wound bearings in oscillating, high-load applications also can be improved by increasing both shaft smoothness and shaft hardness.

Similar improvements in bearing life are also possible if ground shaft surfaces are polished to a smooth finish.

Often the wear debris in a filament-wound bearing identifies whether the shaft surface finish is sufficiently smooth. For instance, a fine brown powder indicates that bearing wear is normal. If the shaft is too rough, however, the bearing wear debris resembles wood shavings.

such as hydrodynamic, fluid film, hydrostatic, boundary lubricated, and self-lubricated are designations for particular plain bearings.

Lubrication

Most bearings operate with a fluid film — oil, another liquid, or a gas. By far the largest number of bearings are oil lubricated. The oil film can be maintained through pumping by a pressurization system — in which case the lubrication is termed hydrostatic. Or it can be maintained by a squeezing or wedging of lubricant produced by the rolling action of the bearing itself — termed hydrodynamic lubrication. If loads are too high or speeds too slow, the hydrodynamic action begins to break down a condition referred to as boundary lubrication.

Hydrostatic lubrication: The main virtue of hydrostatic lubrication is that it can accommodate heavy loads at low speeds because it does not depend upon relative motion to maintain the lubrication film. Instead, lubricant is supplied from a special pump and feed lines to the bearing. The oil is fed through flow restrictors, which generally are stationary. The flow restrictors automatically adjust the oil flow for the applied load. Another advantage of this lubrication system is low deflection in certain load ranges, making it preferred for many high-precision machine tools. The disadvantage of hydrostatic lubrication is its high cost and complexity.

Hydrodynamic lubrication: This form of lubrication occurs more or less naturally in properly finished, sizes, and lubricated holes and shafts. Essentially, rotation of the journal causes it to drag lubricant into a wedged-shaped channel generating a load-carrying pressure. The lubricant in this wedge creates sufficient pressure to keep the journal riding on the oil film. This form of lubrication is generally preferred because it is simple and dependable. Also, the lubrication action improves as speed increases, which in most applications goes hand-in-hand with an increase in loads experienced as speed increases. Its main drawback is an inability to carry heavy loads at low speed and appreciable wear under frequent stops or starts, or motion reversals.

The oil for hydrodynamic lubrication can be fed from an oil reservoir. Or the bearing can be made of a porous metal that is impregnated with oil that "bleeds" to the bearing surface as the shaft rotates. (Most porous-metal bearings, however, operate under boundary or mixed-film conditions.)

Boundary lubrication: This form of lubrication is essentially a breakdown of hydrodynamic action. At high loads or low speeds, the pressure of the hydrodynamic film cannot prevent metal-to-metal contact. So the opposing surfaces partially ride on an oil film and partially rub together as surface high points come in contact. Lubrication is provided by lubricant decomposition products or surface-active additives which form a thin, soft, solid film on the metal surfaces and prevent metal-junction adhesion.

Boundary lubrication is not the most desirable operating mode, yet at times it is completely unavoidable. It is found mainly with slow-moving loads where the cost and expense of a hydrostatic system is not warranted. Hinge bearings in aircraft landing gears, for example, do not move fast enough to develop hydrodynamic films, yet hydrostatic systems would be too heavy, costly, and cumbersome.

Design

Plain bearing design may be simple or complex. It may amount to picking a bearing from a catalog on the basis of *PV* factor, or may require a sophisticated analysis of lubricant flow.

Most slow moving or self-lubricated bearings are boundary lubricated. These are generally simple cylinders or flat washers. Grooves may be added to feed lubricant to load-bearing surfaces in boundary-lubricated bearings. Design variables are material, lubricant, and bearing size. Lubricant and material determine the load limit. Size is based on keeping within the lubricant/material limitations. Bearing performance is difficult to predict and safety factors should be ample as overheating is the most common cause of failure.

With a constant coefficient of friction, the designer has control over two variables — bearing pressure P (load/bearing area), and sliding velocity V (rpm × bearing circumference) — can be combined (PV) as a rough indicator of heat generation. This factor can be used as a starting point for determining materials and size.

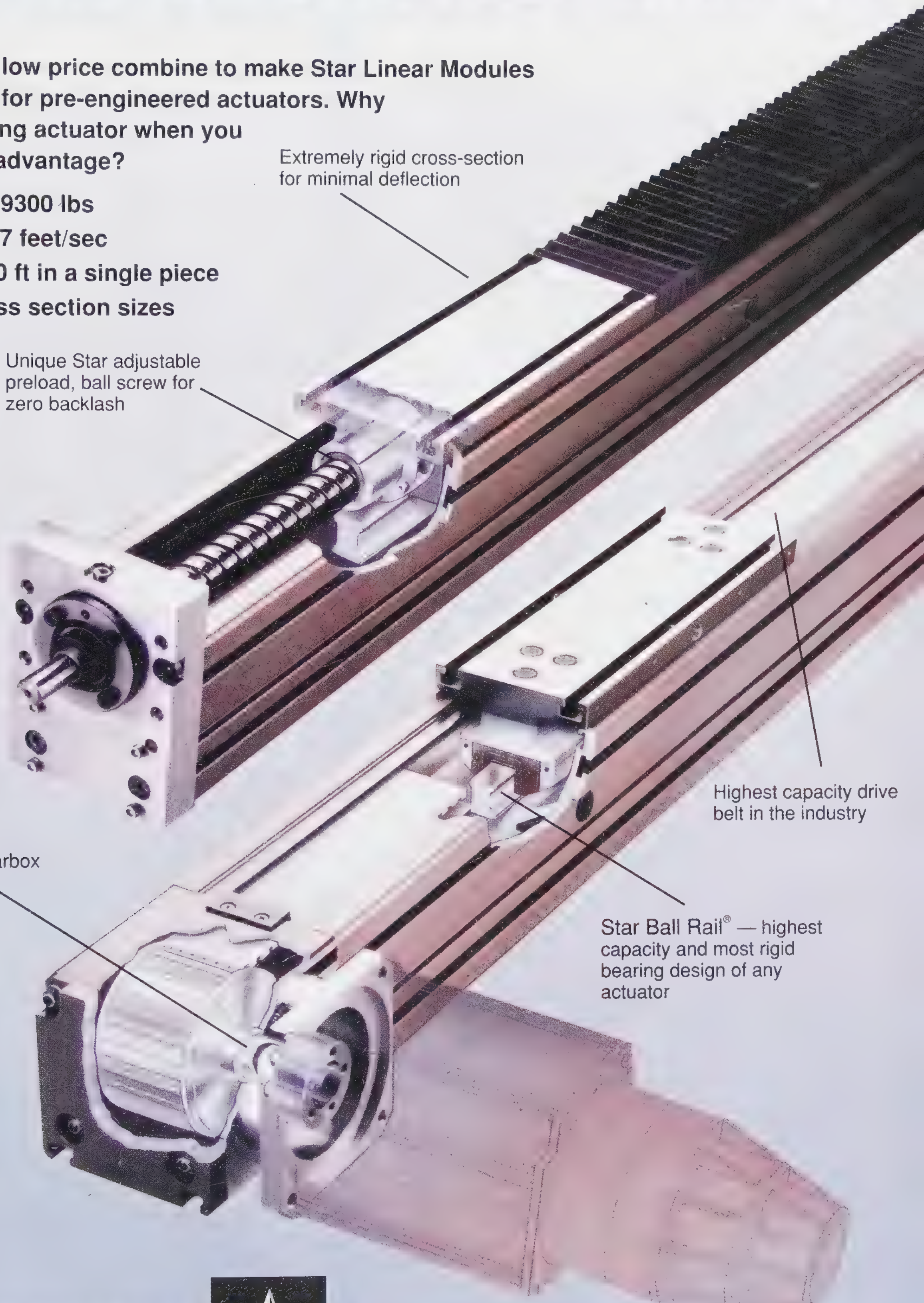
Safe maximum *PV* values for self-lubricating materials have been determined experimentally. *PV* values should be used with caution because they are not constant for most self-lubricating materials over a range of speeds and loads. Thus, a bearing material used for a large bushing operating at low bearing pressure and moderate speed cannot be used for a small bushing operating at high bearing pressure and very low speed. The heat-dissipation characteristics of the large bearing are much different from that of the small bearing.

For many self-lubricating materials — especially plastics — friction varies with speed or pressure. For instance, PTFE shows a decrease in friction coefficient with increasing pressure.

ONLY THE STRONG SURVIVE

High-strength and low price combine to make Star Linear Modules your **only** choice for pre-engineered actuators. Why buy a plastic bearing actuator when you can get the **Star** advantage?

- ☆ Capacity up to 9300 lbs
- ☆ Speeds up to 17 feet/sec
- ☆ Length up to 40 ft in a single piece
- ☆ 4 standard cross section sizes



Extremely rigid cross-section for minimal deflection

Unique Star adjustable preload, ball screw for zero backlash

Ball Screw Drive

Highest capacity drive belt in the industry

Internal Gearbox available

Star Ball Rail® — highest capacity and most rigid bearing design of any actuator

Belt Drive

STAR LINEAR SYSTEMS
800-438-5983

STAR

mannesmann *technology*

9432 Southern Pine Boulevard • Charlotte, North Carolina 28273 • 800-438-5983 • 704-523-2088 • Fax 704-523-4099

Circle 680

STAR LINEAR SYSTEMS

STAR LINEAR SYSTEMS
STAR Ball Rail Systems
Extra-compact linear motion assemblies in 5 accuracy classes
Extremely high load capacity in all four major directions
High rigidity

Ball Rail® Systems

Star Ball Rail Systems are linear motion guideways with high load capacity and rigidity. Developed for machine tools and industrial robots, ball rails provide precision linear motion for many applications. Rails and runner blocks are machined to a high precision, providing components that are interchangeable. Star offers series 15 to 55, and six styles of runner blocks. **Star Linear Systems**, (800) 438-5983.

Circle 701

STAR LINEAR SYSTEMS
Precision Ball Screw Assemblies
with End Bearings and Housings

Ball Screws

Star Adjustable-Preload Ball Nuts eliminate the need for costly double-nut arrangements and provide interchangeability of nuts and screws. Star's high-quality rolled thread screws provide accuracies previously attained only with ground screws. Star Ball Screws are available in diameters from 8 mm to 125 mm. Ground threads are also available. **Star Linear Systems**, (800) 438-5983.

Circle 702

STAR LINEAR SYSTEMS
Lightweight Series
Incorporating STAR Super Linear Bearings

Lightweight Linear Sets

The Star Lightweight Linear Sets combine the high-load capacities and unbeatable smoothness of Star Super Bearings with highly rigid aluminum housings. This new lightweight series is preferred by many design engineers because of its significant weight savings. The lightweight series is available in diameters from 12 mm to 50 mm. Other sizes are still available in Star's standard version. **Star Linear Systems**, (800) 438-5983.

Circle 703

STAR LINEAR SYSTEMS
Linear Slides
with Toothed Belt Drive

Linear slides with toothed belt drive

The Star Linear Systems Slide with toothed belt drive offers low cost, high-speed automation. Toothed belt drive allows speeds up to 118 ips. This, coupled with the proven Linear Ball Bearing/Shaft arrangement, insures long life and reliability. Available either with or without integral shaft supports and lengths up to 3,000 mm. **Star Linear Systems**, (800) 438-5983.

Circle 704

Linear Modules
with integral STAR Ball Rail Systems

Linear modules

Star Linear Modules are complete automation units constructed of low-mass aluminum, with either a steel-reinforced timing belt or precision ballscrew drive for zero-backlash positioning. Capable of speeds up to 16 ft/sec, travels up to 40 ft, and load capacity over 9,000 lbs. Servo and stepper motors/controls available. **Star Linear Systems,** 800-438-5983.

Circle 705

Ball Rail Tables

Star Ball Rail® Table

Ball Rails and precision rolled ball screws with antibacklash nuts provide high-stability and precise positioning. Steel or aluminum construction is available. With option of protective bellows and high-resolution linear encoders, the Ball Rail Table is well suited for the industrial environment of machine tools. **Star Linear Systems**, (800) 438-5983.

Circle 706

STAR LINEAR SYSTEMS
Compact Slides
with integral STAR Ball Rail Systems

Compact Slides

Star Compact Slides are the solution to any space restricted application where high-precision positioning is needed. Incorporating the high-precision Ball Rail bearing components, the Compact Slide is capable of handling heavy loads while maintaining accurate linear motion. Options include ball screw, belt, or pneumatic cylinder. Compact Slides are available in four series sizes. **Star Linear Systems**, (800) 438-5983.

Circle 707

Motion Control Products

Motion control products

Microprocessor-based control products include coordinated and independent axis systems, and bus level board controls. Star controllers are used in applications requiring precise positioning and velocity control of servo and stepping motors. They supply high-performance control logic and motor power in one compact unit. Motors and operator interface devices are also offered. **Star Linear Systems**, (800) 438-5983.

Circle 708

800-438-5983

100% Ball Retention

Star Ball Rails® are designed to allow removal of the Runner Blocks with full ball retention. This is possible due to Star's superior injection molding process. Both rails and Runner Blocks are interchangeable — each element can be ordered individually and assembled in the field, eliminating the need for matched sets. Star Ball Rails® offer the highest stiffness and load capacity of any linear ball bearing, with 6 meter single piece rail lengths. Call or write today to receive your free catalog.

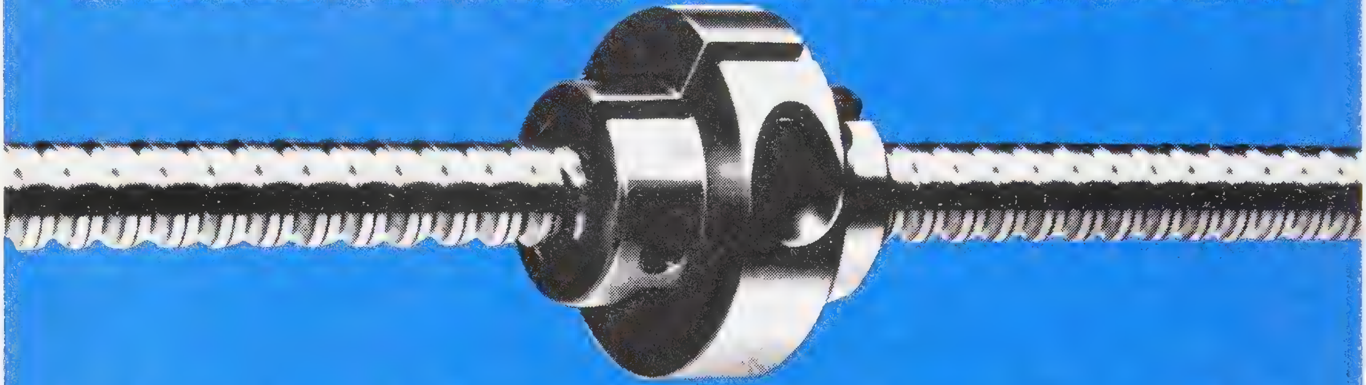
800-438-5983

STAR LINEAR SYSTEMS STAR

9432 Southern Pine Boulevard · Charlotte, NC 28273 · 704-523-2088

Circle 282

Unmatched Precision



Star's Adjustable Preload Ball Screw is the only ball nut Assembly that lets you adjust preload right in your facility. The ball nut and screw need not be matched, giving you off-the-shelf availability. Star's Adjustable Ball Screw Assemblies replace costly double-nut arrangements and save you money without compromising stiffness. End result—a zero backlash system that's less expensive. Read all about it in our free catalog. Just call or write today to receive your copy.

800-438-5983

STAR LINEAR SYSTEMS

STAR

9432 Southern Pine Boulevard • Charlotte, North Carolina 28273 • 704-523-2088

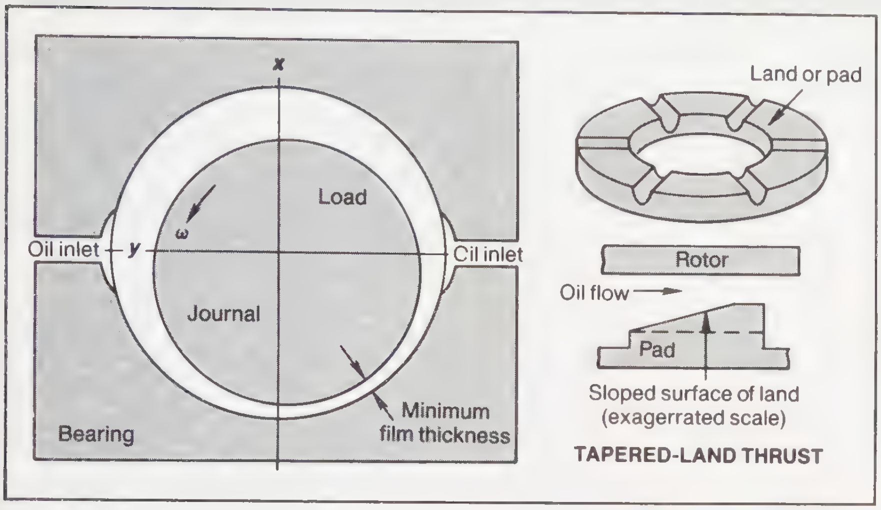
Circle 283

HYDRODYNAMIC BEARINGS

There is some specific clearance between journal and bearing so that at rest, the journal sits on the load line at the center of the bearing. As the journal rotates, it "rides" along the arc of the bearing until it reaches a new equilibrium point, the journal and bearing form on converging wedge-shaped clearance, into which oil is swept by the motion of the journal. Therefore, the sweeping action results in enough pressure to support the journal and keep it from contacting the bearing.

A suitable flat-surfaced bearing material can support a thrust reaction from the end of a rotating shaft and serve as a thrust bearing. The lubrication mode is likely to be boundary or mixed-mode with characteristics less desirable than those of a full fluid film. To operate under full fluid film, the bearing surface must set up hydrodynamic action. In the tapered-land thrust bearing, hydrodynamic action is produced as the rotor or shaft end sweeps oil along the land and up the slope of the lands where it is compressed into a full hydrodynamic film.

A tilting-pad bearing is essentially a tapered-land bearing with load pads mounted on pivots that allow the pads to self-adjust to some optimum taper angle.



TAPERED-LAND THRUST

For shaft rotation in one direction, the pivot points can be placed to provide rotor lift-off at minimum speed (thus minimizing wear). For shafts that rotate in both directions, the pivot is placed in the middle

One modification to tilt-pad bearings, both journal and thrust, adds an oil outlet to the leading edge of the pad. This admits lubricant directly into the fluid film at the leading edge of the shoe. By supplying cool, undiluted lubricant into the hydrodynamic wedge, bearing power loss and babbitt temperatures are significantly reduced. This modification, however, requires that the shaft rotate only in one direction.

For boundary-lubricated bearings using an oil or grease lubricant, a more reliable criterion is maximum bearing stress capacity. Most applications involve relatively slow speeds, making bearing stress the more important variable.

Hydrodynamic bearings

Journal bearings: The theory for this design is complex. It involves optimizing clearances, bearing length, minimum film lubricant, viscosity, flow rate, and inlet slots. Design equations are available, but their solution is time consuming unless done on a computer. Fortunately, these equations have been reduced to chart form, and a wide variety of design problems can be solved with various charts in the literature.

Effective viscosity for the bearing should be obtained from the mean oil operating temperature. Using mineral oil-based lubricants, this temperature typically ranges from 120 to 180°F, but should be less than 250°F. As an approximation, an oil temperature rise of 20°F above the inlet can be assumed. But, most accurate results are obtained from actual field experience. Mean oil temperature is not indicative of maximum bearing metal temperatures.

Oil flow rates are determined from the oil temperature rise and power loss. When the required oil flow is determined, an estimate should be made as to whether the required amount of oil is drawn through the clearance space in the bearing.

Minimum film thickness is often shown on design charts and is found from $(1-\epsilon)c$ where ϵ = eccentricity ratio and c = bearing clearance. However, an acceptable minimum value is not shown because it depends on factors such as surface roughness and type of loading. There is no substitute for minimum film values that have proven successful in similar applications.

High pressures and temperatures generated in a hydrodynamic film should be considered when selecting bearing materials. Bearings subjected to cyclic stresses can fail by fatigue.

The bearing material should also be compatible with the journal material so that when metal-to-metal contact occurs at starting and stopping, minimal surface damage occurs.

Hydrodynamic instability occurs when a journal does not return to its established equilibrium position or attitude if momentarily displaced. Shocks or vibrations produce an instability in which the journal whirls around the bearing axis at less than one-half journal speed. This instability is known as half-speed whirl and occurs in lightly loaded, high-speed bearings. The problem also occurs in vertical-shaft journal bearings where there is essentially no radial load on the bearing. The extent of shaft whirl ranges from unnoticed to a violent reaction that destroys the bearing.

If the bearing speed, journal diameter, and load are fixed, stability can be increased by reducing bearing length or the lubricant viscosity. If whirl cannot be avoided, a lobed bearing may alleviate the situation. A tilt-pad bearing is the most stable radial bearing configuration, but it is costly.

Bearing stiffness and damping capacity are important considerations when making machine vibration and critical shaft speed analyses. Stiffness is the reciprocal of the journal displacement with applied load. Damping is the force resisting journal radial motion.

Bearing stiffness can be considered a displacement-force relation. It varies with displacement of the journal, and can be estimated by determining eccentricity ratios for a series of applied loads and calculating the slope of the resulting displacement load curve.

From consideration of the damping capacity, shaft critical speed may be reduced from that predicted on the basis of a rigid metal support system.

Thrust bearings: The design of a hydrodynamic bearing to sustain thrust is as complicated as the design of a journal bearing. Complete analysis requires consideration of heat generation, oil flow, bearing material, load capacity, and stiffness.

In a tapered-land thrust bearing, design variables include the slope, width, and length of the lands. Slope of the land, usually defined as the ratio of total "rise" to gap thickness, is normally between 0.5 and 2.0. The running film thickness usually is less than a thousandth of an inch, and land tapers are usually only 0.1 to 0.2 mil per inch of pad length.

Fixed geometry bearings, such as tapered land, are designed for a specific set of operating conditions. Deviations from these conditions result in less than optimum bearing performance.

Unlike fixed geometry bearings, tilting-pad thrust bearings have the ability to self-adjust the slope or tilt to accommodate varying operating conditions. Equalizing tilting pad thrust bearings permits even thrust-load distribution over pads. This equalization handles misalignment and deflections in the housing and seating.

The six types of thrust bearing are flat land, step, taper, tilting pad, spring supported, and hydrostatic. The first five are called hydrodynamic bearings because they generate oil pressure when a thrust face on a rotating shaft pumps oil by shear into a zone of reduced downstream clearance and increased outflow resistance. When thrust load increases, film thickness drops until a new balance between inflow and outflow is reached, raising pressure until the higher bearing load is balanced. The hydrostatic thrust bearing uses a separate oil pump to supply pressurized flow to balance outflow.

Flat-land bearings are the simplest to fabricate and the least costly. Thus, they are a first choice for simple positioning of a rotor and for light loads in machinery such as electric motors, appliances, pumps, and crankshafts.

However, flat-land bearings carry less load than the others because flat parallel planes do not directly provide the required pumping action. Instead, their action depends on thermal expansion and warping of the bearing material induced by heating from passing oil. The slight oil wedge shape then gives a load rating of about 10 to 20% of that expected with other bearing types.

Step bearings also have a relatively simple design. With a coined or etched step, they lend themselves to mass production in small sizes in the form of bearings and thrust washers. Step height for about the minimum film thickness, commonly about 0.001 in. Circumferential length of the raised area beyond a step is ideally 28% of the total bearing segment.

Step-thrust bearings are well suited for low-viscosity fluids such as water, gasoline, and solvents. Minimum film thickness in these application is so small that features such as pivots and tapers are impractical.

Step height must be small enough for good load capacity, yet large enough for the bearing to accommodate some wear without losing its load capacity by becoming smooth and flat. Fortunately, load capacity drops gradually for steps greater than optimum height, so that some wear actually improves performance for higher steps. Still, step erosion by trapped contaminants is sometimes a problem in large step bearings.

Tapered-land bearings are reliable, compact designs for a large variety of mid to large-size high-speed machines such as steam and gas turbines, compressors, and pumps. As with step bearings, taper height normally should be about equal to the minimum film thickness. To minimize wear during starting and stopping, and at low speeds, a flat land is commonly machined at the trailing edge. Load capacity is highest when the land length ranges from 15 to 30% of circumferential length of each bearing segment.

Because the operation of these bearings is sensitive to load, speed, and lubricant, they are typically designed to meet narrow operating conditions in specific machines.

Tilting-pad thrust bearings are used increasingly in marine drives, turbines, compressors, and pumps over much the same range of applications as tapered-land designs. They commonly have a central supporting pivot, and each of the six to 10 or more bearing segments adjusts freely to form a nearly optimum oil wedge even with widely varying loads, speeds, lubricants, and rotation in both directions. Leveling linkages to equalize load carried by individual bearing pads provide a further advantage over tapered-land designs by accommodating some misalignment.

Off-the-shelf units are available to match rotor shaft sizes from about 2 to 12 in., and custom designs can be adapted to a wide variety of applications including diameters up to the 120 to 170-in. range. Recent trends toward offset pivot, substituting copper for steel backing of a babbitt bearing surface, and nonflooded lubrication have significantly increased load capacity of tilting-pad bearing with some cost penalty.

Springs and other flexible supports for thrust segments are used for large bearings ranging to 10 ft or more in diameter and carrying millions of pounds of thrust. Flexible mounting avoids high load concentrations at pivots in large tilting-pad bearings. However, mechanical pivots provide similar advantages. These include automatic adjustment to provide a hydrodynamic supporting oil wedge for varying operating condition, and accommodation of misalignment.

Hydrostatic bearings

The design of hydrostatic bearings is more complex than that of self-acting types because of the greater number of components requiring design decisions. The pressure pads in hydrostatic bearings are the load-bearing elements.

Most hydrostatic systems (thrust or journal bearings) use several evenly spaced pads so nonsymmetrical load distributions can be handled. To estimate performance, pads can be treated separately. Pressure is maintained in the recess by fluid pumped through a flow restrictor. The pressure lifts the rotor until flow out of the recess and over the land equals flow in. A constant gap is maintained for a given recess pressure and bearing load. The gap establishes the volume of fluid that is pumped through the bearing. An alternative design is to connect a fluid displacement pump (gear or vane type) directly to each pocket without flow restriction.

Pressurizing pump power can be estimated from the product of pad pressure and total flow through the pads. For an estimate of lubricant flow rate, a gap (or film thickness) is assumed — typical values are 0.001 to 0.002 in.

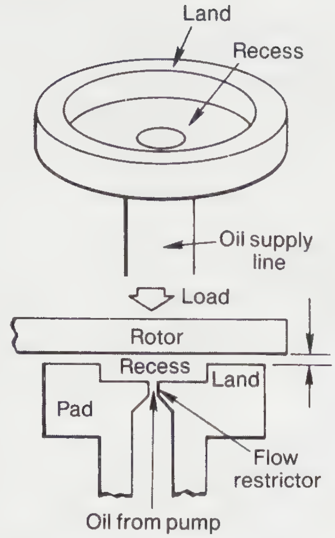
Design of flow restrictors influences bearing stiffness, pumping power, supply pressure, and lubricant flow. A flow restrictor is necessary to provide a pressure drop between the supply manifold and the pad recesses to ensure that pressure requirements in any given pad never exceed supply pressure. A bearing with restrictors is called a "compensated bearing." Action of the restrictors is such that if the thrust load is centered, pressure in all the pads is equal and lower than pump pressure. If the load is off center, the gap thickness decreases somewhat on the loaded side, and flow from the pad there decreases. This results in an increase in loaded-pad pressure and a decrease in pad pressure on the opposite side, so that the runner automatically seeks a nearly level attitude.

Three compensators are used in hy-

HYDROSTATIC BEARINGS

These bearings consist of an external pressure supply, flow restrictors, pressure pads, and clearance space. Oil flow from the pump creates sufficient pressure at the recess and land to lift the load (rotor) and keep it from coming into contact with the land. This clearance is maintained even when the rotor is not moving, resulting in no wear.

Load support per pad is approximately a linear function of the ratio of recess area to pad area. The larger the ratio, the higher the load support. However, flow out of the pad along with pumping requirements increases with this ratio. Flow is approximately proportional to the cube of the gap. Proper design of pads, therefore, requires optimization of the ratio of recess to pad areas and recess pressure to minimize pumping requirements.



drostatic bearings — orifice, capillary, and variable-flow restrictor. The first two are fixed-flow restrictors; the third is a valve which automatically adjusts flow as it senses pressure differentials between pads. The variable-flow restrictor provides a stiffer bearing system, but is more expensive than fixed-flow restrictors. Sizing of the orifice or capillary for optimum performance is an essential part of the design of a compensated hydrostatic bearing.

Hydrostatic bearing design requires adjustment of a number of parameters including pad geometry, restrictor size, supply pressure, and journal bearing clearance to optimize performance.

Friction

The frictional properties of any plain bearing depend on the lubrication system. Either hydrodynamic or hydrostatic lubrication can provide low friction. The lowest friction levels are attained in gas bearings.

Friction in hydrodynamic and hydrostatic bearings is a function of lubricant viscosity and shear rate. Shear rate increases with increasing rotational speed and decreasing film thickness. Friction coefficient is generally below 0.001.

Self-lubricated bearings vary widely. It is difficult to predict performance for a given bearing/lubricant system. The range of coefficients of friction is 0.01 to 0.10 for boundary lubrication and 0.01 to 0.3 for self-lubrication.

Caution must be used when applying friction coefficient handbook data. Conditions under which the values were measured should be known, and duplicated in the application. Coefficient of friction tends to increase with increasing surface roughness, dryness and cleanliness of surfaces, and with decreasing temperature.

Wear

Wear of plain bearings is influenced by the state of lubrication and, conversely, wear characteristics influence the various lubrication states.

Hydrostatic bearings do not wear if operating properly because the bearing surfaces are separated by a film of oil. Erosion of flow restrictors in hydrostatic bearings with high flow rates eventually causes failure. Plugging of flow restrictors by wear debris can cause catastrophic failure. In gas-lubricated, externally pressurized bearings, occasional rubs and resulting wear can occur under impact and vibration loads.

Hydrodynamic bearings wear very slowly. Wear occurs during start-up and slowdown when speed is too low to produce sufficient fluid pressure to support the bearing surfaces on a lubricant film. If hard debris imbeds in a babbitt or plastic bearing and protrudes above the bearing surface, the journal can wear seriously during start-up.

In a severe and catastrophic type of journal wear — known as wire wooling — the journal surface is machined by hard scabs of wear debris that pack into the babbitt surface. In this failure the journals are deeply grooved and can no longer generate a hydrodynamic film.

Boundary-lubricated and self-lubricated bearings wear much faster than fluid-film bearings. Self-lubricating plastic bearings wear at higher rates than boundary-lubricated, metal-alloy bearings.

In reciprocating load application, babbitts are subject to fatigue damage in which pieces of the babbitt metal spall out of the surface. This might be considered as a catastrophic type of failure after a prolonged (but undetectable) period of wear buildup. Babbitt fatigue is most likely in bearing subjected to reciprocating or vibrating loads.

Babbitts and leaded bronzes are also susceptible to cavitation erosion. This is a form of wear in which shock waves, from gas bubbles collapsing in the lubricant, produce surface pits. Eventually, the removal of surface material impairs performance. Cavitation erosion has a characteristic lacy appearance and often is found around lubrication feed holes and slots in bearings subjected to vibratory or impact loading — such as in internal combustion engines.

Heat

Heat is generated either by shearing of the oil film or by rubbing contact. In hydrostatic and hydrodynamic bearings, heat generating at running speeds is the result of oil shear, and the amount of temperature rise can be estimated if oil viscosity and shear rates are known. Temperature can be regulated by controlling the oil flow through the bearing or by using external cooling.

High-speed and close-clearance fluid-film bearings are difficult to cool. The flow rate through a journal bearing consists of a hydrodynamic portion and a hydrostatic portion. The hydrodynamic flow is proportional to $RC\omega/2$ multiplied by a constant which is a function of load or eccentricity ϵ. Here, R = bearing radius, in.; C = clearance, in.; and ω = journal speed, rpm. The hydrostatic flow is proportional to feed pressure and is also a function of feed groove shape, cube of oil-film thickness, and local viscosity.

Boundary-lubricated and self-lubricating bearings are more sensitive to sliding velocity than fluid-film types because the coefficient of friction is as much as ten times greater in the first two. Frictional heating is a function of bearing pressure, sliding velocity, and coefficient of friction. Therefore, if the coefficient of friction remains constant for a range of loads and speeds, a rough indication of heat load is provided by the *PV* factor.

Most plastic bearing materials are sensitive to *PV* because of their low thermal conductivities and high thermal-expansion rates.

Rolling-element bearings

Rolling-element bearings consist of ball bearings and roller bearings. Ball bearings typically have higher speed and lower load capabilities than roller bearings. Both types are available as unmounted or premounted assemblies. Premounted bearings provide proper bearing support and reduce design and assembly time, but they are bulkier and more costly than unmounted bearings.

Ball bearings

Ball bearings have three classes: radial, thrust, and angular contact. Angular-contact bearings combine radial and thrust loads, and are used where precise shaft location is needed. Uses of the other two types are described by their names: radial bearings for radial loads, and thrust bearings for thrust loads.

Radial bearings

Conrad or deep-groove bearings are the most widely used ball bearings. In addition to radial loads, they carry substantial thrust loads at high speeds, in either direction. They require careful alignment between shaft and housing.

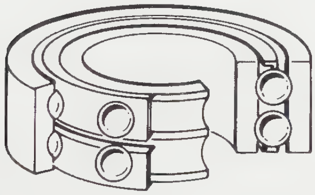
The ball complement of a deep-groove bearing is limited to the number of balls that can be packed into the annular space between the rings with the inner ring displaced radially. The inner ring is then snapped into place, and the retainer assembled around the balls. This limits the load-carrying ability of the bearing, since capacity is proportional to the number of balls to the ⅔ power.

Although the majority of deep-groove bearings are made to ABEC-1 specifications, higher-precision bearings are readily available. Unless the application involves high speeds or some other unusual feature, ABEC-1 bearings normally suffice. Additional expense for higher-grade bearings is considerable.

Maximum capacity or filling notch bearings have about 20 to 40% more radial load capacity than deep-groove bearings. The increased capacity comes from additional balls that are inserted through the filling notch. Except for the filling notch and the extra balls, they are geometrically identical to deep-groove bearings.

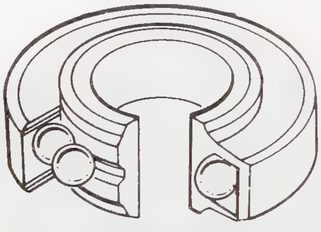
But the same filling notch that permits an increased radial load cuts thrust capacity to about one-third that of deep-groove bearings. At higher thrust loads, balls start to contact the notch. For the same reason, tolerance to misalignment is considerably less

RADIAL BALL BEARINGS



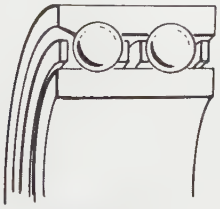
DOUBLE-ROW DEEP GROOVE

Double-row bearings have bore sizes from about 0.4 to 4.3 in., and have about 50% more radial load capacity than that of deep-groove single-row bearings.



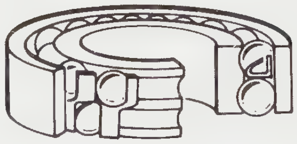
AIRCRAFT CONTROL

These full-complement bearings have static capacities 2 to 3 times higher than that of deep-groove bearings. Bore sizes range from 0.19 to 1.25 in.



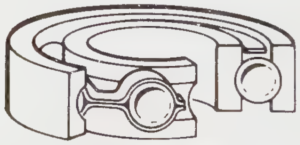
DOUBLE-ROW MAXIMUM CAPACITY

Maximum-capacity types can tolerate 3' of misalignment.



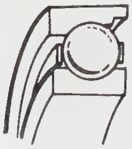
INTERNAL SELF-ALIGNING

Internal alignment features limit radial load capacity to about 70% of that for deep-groove bearings, but permit misalignments up to 2°30'.



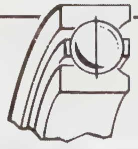
DEEP-GROOVE

Probably the most common ball bearings, deep-groove, or Conrad bearings have bore sizes ranging from 0.12 to over 41 in., and can accommodate misalignments up to 15'.



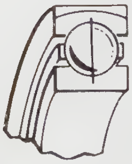
COUNTERBORED

Counterbored bearings have bore sizes ranging from 0.1 to almost 8 in., and can tolerate misalignments up to 5'. Thin-section counterbored bearings are called magneto bearings.



MAXIMUM CAPCITY

The filling notch on these bearings allows a fuller ball complement and raises radial load capacity by 20 to 40% compared to deep-groove bearings, but cuts tolerance to misalignment to about 3'. Bore sizes range from 0.3 to over 5 in.



EXTERNAL SELF-ALIGNING

External alignment features allow bearings to match the load capacity of deep-groove bearing with high tolerance to misalignment.

NYLINER PLUS Composite Bearings

More Performance For Your Plain Bearing Dollar

New NYLINER PLUS* bearings from Thomson Industries combine all the performance characteristics of our standard polymer bearing line with the benefits of advanced thermoplastic composites for performance at a cost that's hard to beat.

Pressure/Velocity Ratings

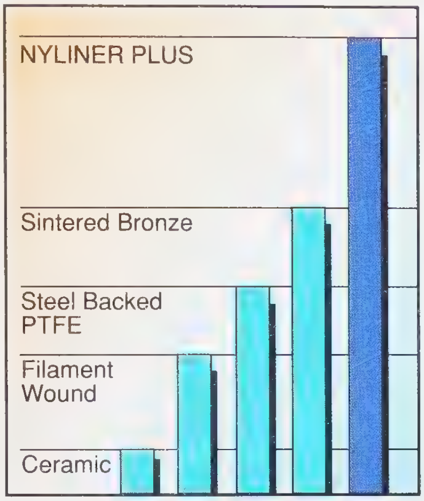
NYLINER PLUS bearings have PV ratings in the range of 10,000 to 43,000 — ratings previously only available with expensive and difficult to use bearings.

High Operating Temperatures

Our unique engineering polymers enable NYLINER PLUS bearings to withstand temperatures over 500°F. This means you get higher ambient temperature possibilities and greater resistance to heat caused by running friction.

Plain Bearings

Load Rating Per Dollar



Lower Friction

With the addition of sophisticated internal lubricants, we can offer NYLINER PLUS bearings with coefficients of friction as low as .06 without additional lubrication.

Increased Bearing Life

NYLINER PLUS bearings are made of tough, durable combinations of high performance resins and internal reinforcement systems. They provide extremely long, trouble-free operating life.

NYLINER PLUS bearings should be your first choice for high performance, high reliability applications. For immediate assistance
Call: (516) 883-8000
Fax: (516) 883-9039
or write:
Thomson Industries, Inc.,
Port Washington, NY 11050.

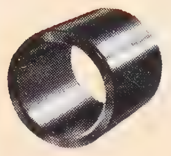
THOMSON*
First in Plastic Bearing Technology

*Trademark of Thomson Industries, Inc., THOMSON is registered in U.S. Patent and Trademark Office and other countries.

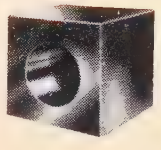
Circle 284

ELIMINATE expensive DOWNTIME
– install GRAPHALLOY Bushings
for long, uninterrupted life.

GRAPHALLOY Bushings operate in temperatures ranging from *minus* 450°F. to 750°F. with *no oil* lubrication. The unique self-lubricating property of GRAPHALLOY enables it to operate dry or submerged, for long, uninterrupted self-lubricated life. GRAPHALLOY Bushings contain no oil to burn or contaminate.

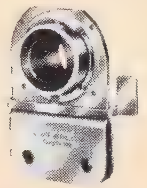


Plain



Block Bushings

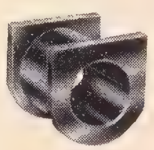
Metal-backed Bushing



Hanger Bearing

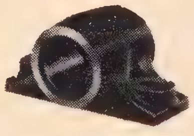
What's YOUR Bearing PROBLEM?

We have SOLUTIONS!

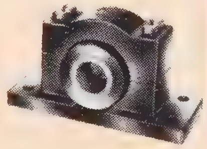


Double-flanged & Split

Flange Assembly



Pillow Block



Self-Aligning Pillow Block

With GRAPHALLOY You're a Winner ALL WAYS!

1) **Self-lubrication** for long life. No oil, no fumes, odor or sparking. Deposits a thin friction-inhibiting film.
2) **Low/High temperature** use... operates at temperature from liquid helium to over 750°F.
3) **Low coefficient** of friction. Solid GRAPHALLOY is constant throughout.
4) **Submerged.** Graphalloy will not expand or wash away...in salt water, gasoline, jet fuels, cleaning fluids, solvents, bleaches, caustic solutions, dyes, hydrocarbons, liquid gases and most chemicals...even molten metals.
5) **High Loads**...Graphalloy is stable, where grease or oil would be squeezed out. Does not cold flow as plastics do.
6) **No Corrosion.** Grades of GRAPHALLOY are available to withstand most environments.
7) **Low Coefficient of Thermal Expansion,** half that of steel. Cannot seize shaft at low temperature.
8) **High Speeds**...for pumps, dentist drills, centrifuges.
9) **Current-carrying bushings** for grounding and power circuits. **Think of GRAPHALLOY for electrical brushes too!**

In These Industries:

Autoclave
Bakery
Blending
Chemical
Conveyor
Cryogenic
Digester
Drug
Dryer
Dust Collector
Evaporator
Explosives
Fertilizer
Food
Hot Rolls
Leather
Machinery
Meter
Mill
Mixer
Nuclear
Oven
Paper & Pulp
Petrochemical
Petroleum
Photographic
Printing
Pump
Refrigeration
Sewage & Waste
Steel
Textile
Valve
Ventilating
Water Treatment
Weighing

Circle 285

GRAPHALLOY®

Engineered Solutions since 1913

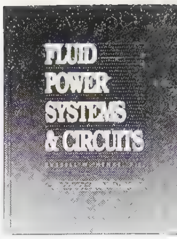
GRAPHITE METALLIZING Corporation
1053 Nepperhan Avenue, P.O. Box 110
Yonkers, New York 10702

Tel. 914-968-8400 FAX 914-968-8468

©Graphite Metallizing Corporation 1984

FLUID
POWER
SYSTEMS &
CIRCUITS

by Russ Henke



Order your review copy toll-free 80
321-7003 In Ohio call 216/696- 7000

Written for design engineers, plant eng
neers, technicians, maintenance pe
sonnel, and those who need to unde
stand and apply fluid power circuits,
this new book covers circuit analysis
and design for:
- Constant and demand flow controls
- Directional controls
- Pressure controls
- Load and load analysis
- Selecting valves, pumps, and auxiliary components.

Completely illustrated . . . clearly writte
. . . to show how to analyze interactio
of system components and how to pu
an entire design together to meet antic
pated loads and operating require
ments. Recommended for college lev
instruction.

1983 ....400 pages ....
hardbound $49.5

To order, call on our toll-free line 80
321-7003 or complete the coupon be
low and mail to:

Penton Education Division
1100 Superior Avenue
Cleveland, Ohio 44114

Please send me _____ copies of th
book Fluid Power Systems & Ci
cuits by Russ Henke. I understan
that I may review the book for 1
days and, if not completely satisfie
I may return it for full refund o
credit.

☐ I enclose my payment and sav
shipping and handling charges (i
the U.S. only).

☐ Bill my company for the book
and include shipping and handlin
charges. My purchase order is en
closed.

Charge my ☐ MasterCard
☐ Visa ☐ American Express car

Acct. No. ________
Exp. date ________

Name ________

Company ________

Address ________

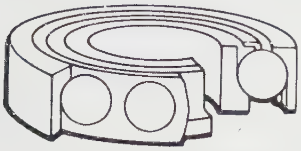
City ________

State ________ **Zip** ________

Signature ________

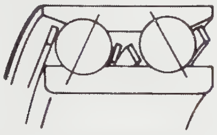
Penton Education Division
1100 Superior Avenue • Cleveland, OH 44

ANGULAR-CONTACT BALL BEARINGS



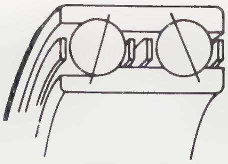
ONE-DIRECTION THRUST

These bearings cover bore sizes from 0.4 to 12.6 in., and can tolerate misalignments up to 2'. They carry about the same radial loads as deep-groove bearings, but about 2.3 times more thrust load (if thrust is applied in the proper direction).



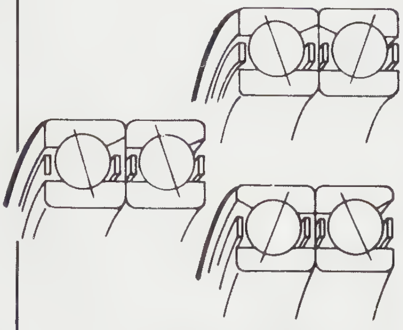
DOUBLE-ROW

Double-row, angular contact bearings have bore sizes up to about 5.5 in. They provide about 50% greater capacity than one-directional bearings and considerably more resistance to overturning moments, but can tolerate no misalignment.



DOUBLE-ROW MAXIMUM COMPLEMENT

Maximum-complement types are available in bore sizes up to 4.3 in. They have the same operational characteristics as double-row angular-contact types.



DUPLEX THRUST

Duplex thrust bearings are simply two match-ground one-direction thrust bearings mounted together to obtain two-directional thrust capacity or to increase one-directional thrust capacity.

than that of a deep-groove bearing.

Magneto or counterbored bearings are widely used in small motors. Except for the removal of one shoulder of the outer ring, they are identical to deep-groove bearings. The separable feature permits separate mounting of inner and outer rings. Radial and thrust capacities range from slightly less to about 30% more than deep-groove bearings.

Airframe or aircraft-control bearings transmit heavy radial loads under intermittent oscillation. As their name implies, they are used in aircraft control mechanisms. They are made in a number of different types and styles to meet special needs, but the majority are full-complement cageless bearings.

Self-aligning bearings come in internal and external types. Internal bearings have an outer-ring ball groove ground to a spherical surface. This surface makes the bearing insensitive to misalignment, but increases raceway contact stresses, which cuts load capacity.

Externally self-aligning bearings have a spherical surface on the outside of the outer ring, which matches a concave spherical housing. External bearings have better load capacity than internal, but demand greater radial space.

Double-row, deep-groove bearings embody the same principle of design as do single-row bearings. However, grooves for the two rows of balls may be positioned so that the load lines through the balls converge outwardly or inwardly. Inwardly converging bearings deflect more under moment loading, but can stand more misalignment. Some bearings, particularly the inwardly converging type, have filling notches so extra balls can be added to increase load capacity. These filling notches limit the thrust capacity in one direction.

Double-row bearings can be used where high radial and thrust rigidity is needed, and space is limited. They are about 60 to 80% wider than comparable single-row deep-groove bearings, and have about 50% more radial capacity.

Angular-contact bearings

One-directional thrust bearings can support heavy thrust loads in one direction, combined with moderate radial loads. High shoulders on the inner and outer rings provide steep contact angles for high thrust capacity and axial rigidity. Bearings with contact angles from 15 to 40° are available, but contact angles above 30° are not recommended for high-speed applications.

Duplex bearings are supplied in matched pairs, and should never be separated and used with single bearings from other pairs. They are used because most applications require support for bidirectional thrust loads. Duplex bearings are match-ground, so their inner and outer ring faces have identical stickout under a nominal thrust load.

When a duplexed pair is mounted either back-to-back or face-to-face, the bearings become preloaded. The preload depends on original bearing stickout and load-deflection characteristics.

Preloading provides a stiffer bearing system with precise shaft location. On the other hand, after application of a thrust load, the working bearing must carry a higher load. In applications with high-acceleration starts, bearings must be preloaded to prevent ball skidding. As a rule of thumb, use a preload equal to about half the applied thrust load to avoid unloading the reverse-thrust bearing.

Duplex back-to-back and face-to-face mounts are functionally identical, except for their resistance to moment loading. Back-to-back arrangements are more resistant to moment loading and shaft bending, because the lines of contact intersect outside the bearing envelope.

Duplex bearings are also used in tandem arrangements for very high unidirectional thrust loads. Stackups of three or more bearings are used when a simple arrangement is impossible.

Double-row, angular-contact bearings are the equivalent of two single-opposed angular-contact bearings. They have lines of contact converging outside the bearing envelope (as in a back-to-back duplex pair) or inside the envelope (as in a face-to-face pair). Bearings with externally converging lines of contact are much more resistant to overturning moments.

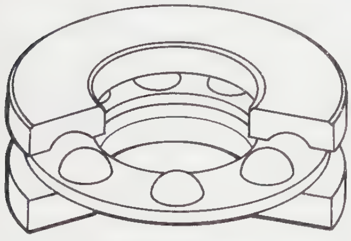
Thrust capacity of the double-row maximum-capacity bearing is somewhat limited in one direction because of the filling notch.

Thrust bearings

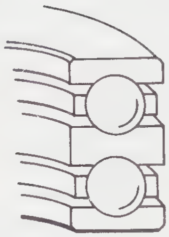
In a sense, thrust bearings can be considered to be 90° angular-contact bearings. They support pure thrust

THRUST BEARINGS

With bore sizes in the range of 0.2 to 46.5 in., these bearings can accept about twice as much thrust and three times the rotational speed of flat-race bearings. However, they cannot tolerate misalignment or eccentricity.



GROOVED-RACE

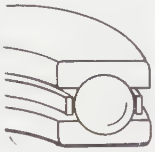


TWO-DIRECTIONAL GROOVED-RACE

These bearings have bore sizes ranging from 0.6 to 8.6 in., and can accept thrust from both directions.

FLAT RACE

These bearings have bore sizes in the range of 0.2 to 3.5 in. Although they do not tolerate misalignment, they can accept some rotational eccentricity.



loads at moderate speeds, but for practical purposes, their radial load capacity is nil.

Because they cannot support radial loads, ball thrust bearings must be used with radial bearings. Even slight misalignments can cause drastic load concentrations, so the bearings must be kept square with the shaft or used with self-aligning seats. However, the ability of the self-aligning seat to follow shaft wobble or misalignments is still quite limited.

Flat-race bearings consist of a pair of flat washers separated by the ball complement and a shaft-piloted retainer, so load capacity is limited. Contact stresses are high and torque resistance is low.

The prime advantage of flat-race bearings is that they permit eccentricities, since there are no grooves to restrain one race from wandering slightly with respect to the other.

One-directional, grooved-race bearings have grooved races very similar to those in radial bearings. Thrust capacity is about twice that of the flat-race bearing, and limiting speed is about three times as high. However, limiting speed is still quite low because balls spin at high speeds.

Two-directional, grooved-race bearings consist of two stationary races, one rotating race, and two ball complements. Their characteristics are identical to those of the one-directional bearing, except that they can support thrust in both directions.

Thrust bearing application

Type	OD (in.)	Unit load (psi)
Flat land	0.5-20	30-100
Step	0.5-10	100-300
Tapered land	2-35	150-300
Tilting pad	4-120	250-700
Spring supported	50-120	350-700
Hydrostatic	3-50	500-3,000

Thin-section bearings

There are three types of thin-section bearings: deep groove, four-point contact, and angular contact. Compared to standard-section ball bearings, all three offer advantages in reduced space requirements and low cost. They are used primarily where shaft location is the major requirement.

As structural components, thin-section bearings behave differently than standard bearings because their bearing rings are quite flexible. Under load, the rings follow the imperfections of shaft and bores, so these components must be geometrically accurate.

The four-point contact bearing can support thrust loads in either direction, and is much more effective in resisting moment loads than the deep-groove design.

Two other designs use an axial split in the outer ring to increase ball complement and radial capacity without sacrificing thrust capacity. One is a full-complement design, the other uses alternating full-size balls and spacer balls. The latter type also has high shoulders on the outer ring to provide integral shields for grease lubrication. Both types are held together with wire bands after assembly.

Roller bearings

The principal types of roller bearings are cylindrical, spherical, tapered, and needle. In general, they have higher load capacities than ball bearings of the same size, and are widely used in heavy-duty moderate-speed applications. However, except for cylindrical bearings, they have lower speed capabilities.

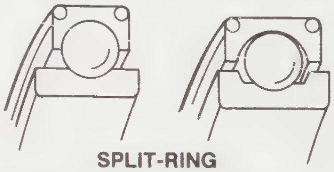
Cylindrical bearings

Cylindrical roller bearings have high radial capacity and provide accurate guidance to the rollers. Their low friction permits operation at high speed, and thrust loads of some magnitude can be carried through the flange-roller end contacts.

Although the rolling elements are called "cylindrical," they are not true cylinders. True cylinders would produce stress concentrations at the ends of the roller-race contact, resulting in high wear and high sensitivity to misalignment. Instead, rollers are usually crowned or end relieved.

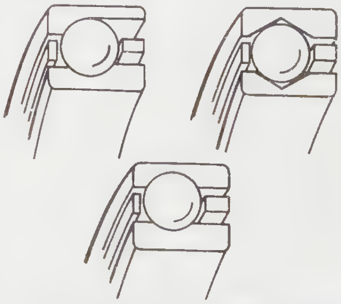
Because they are used for high speeds, cylindrical roller bearings are commonly made in precision grades such as RBEC5, as well as the lower grades. The close tolerances of the higher grades may be needed in precision spindles as well as in high-speed applications.

THIN-SECTION BALL BEARINGS



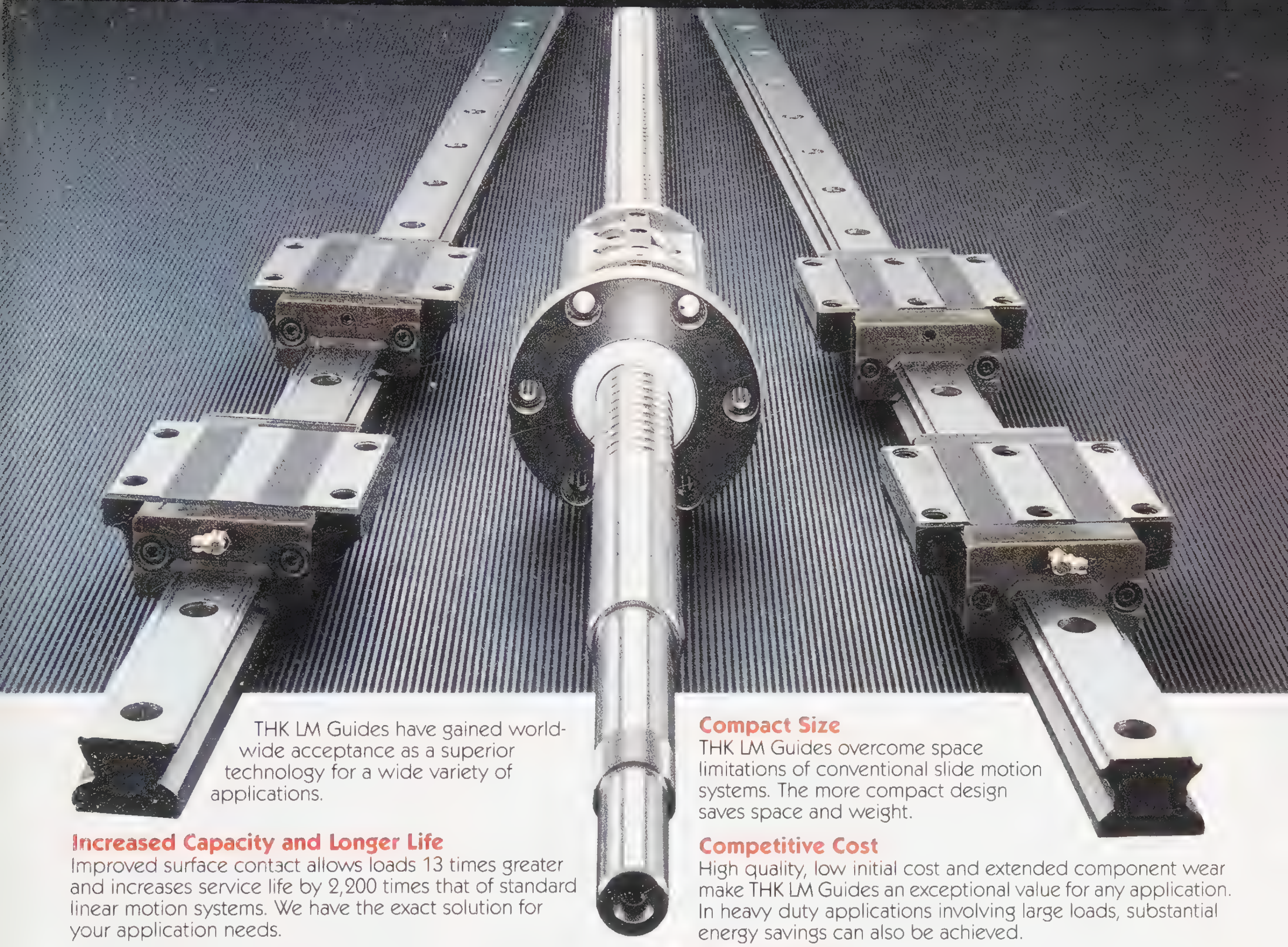
SPLIT-RING

Split-ring bearings have bore sizes up to 3 in. Their higher ball complements give them high radial load capacities.



These designs have bore sizes ranging from 1 to 40 in., and take considerably less space than standard ball bearings.

The THK Advantage: 13 times the load, 2,200 times the life of standard linear motion systems.

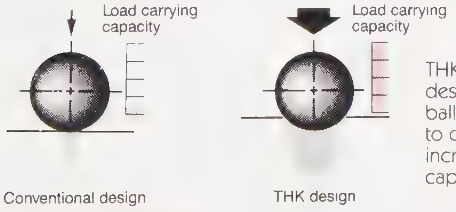


THK LM Guides have gained worldwide acceptance as a superior technology for a wide variety of applications.

Increased Capacity and Longer Life

Improved surface contact allows loads 13 times greater and increases service life by 2,200 times that of standard linear motion systems. We have the exact solution for your application needs.

The implementation of R-groove raceways dramatically increases the ball contact area to the raceway, reducing frictional resistance without accelerated ball wear.



THK's superior design improves ball / raceway contact to dramatically increase application capabilities

Easy Installation

THK LM Guides are preloaded and self-adjusting to reduce installation time to less than one-third that of conventional slide motion systems, saving assembly time and money.

Proven Repeatable Precision

THK LM Guides are precision ground to perform high precision functions over the entire application area. Reliable service is achieved through extended component life.

Compact Size

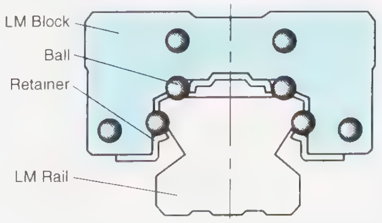
THK LM Guides overcome space limitations of conventional slide motion systems. The more compact design saves space and weight.

Competitive Cost

High quality, low initial cost and extended component wear make THK LM Guides an exceptional value for any application. In heavy duty applications involving large loads, substantial energy savings can also be achieved.

Readily Available

THK maintains an extensive in-stock inventory of all sizes of LM Guides, ensuring fast delivery. To aid in proper guide selection, a staff of fully trained engineers is available for application assistance.



The THK SR design features high load capacity and stiffness

The THK Advantage

The installation of THK LM Guides can provide applications with significantly greater load capacities over a longer service life. To find out how the THK advantage can work for you, contact your local THK Representative or call **(708) 310-1111.**

THK

Circle 286

Unlike ball bearings, cylindrical roller bearings are generally lubricated with oil; most of the oil serves as a coolant.

A persistent problem in high-speed, lightly loaded, cylindrical roller bearings is roller skidding, which can lead to premature bearing failure. One technique to combat skidding is an out-of-round raceway, which pinches the rollers at two diametrically opposite points. Another technique is the use of two preloaded hollow rollers. Both techniques require precise engineering to eliminate loading without introducing other problems.

Nonlocating bearings have either a separable outer ring or separable inner ring, and allow considerable axial movement of the shaft. They must be used with an axially locating bearing such as a ball bearing. Nonlocating bearings have high radial and load capacity, high stiffness, and the highest speed capability of any roller bearing.

One-direction locating bearings also have separable outer or inner rings. But in these bearings the separable ring has a single flange that prevents shaft wandering in one direction. Roller guidance is provided by the double-flanged race. Characteristics are similar to the nonlocating bearings, except for a slightly lower limiting speed caused by the flange.

Two-direction locating bearings may be self-contained or have a two-piece inner ring. The self-contained type has a lower roller complement and lower roller capacity, because it must be filled by displacing the rings and filling the remaining space. The two-piece version has more load capacity, but is more complex.

Full-complement bearings use two snap rings in the nonlocating race to retain the rollers. Usually the outer race is the nonlocating race. Their advantage is high load capacity, but their disadvantage is low speed. The speed limitation results from the high rubbing velocity between adjacent rollers, and limits the bearing to low-speed or oscillatory applications.

Double-row bearings are used where alignment between shaft and housing is very good and high loads are encountered at moderate speeds. They are nonlocating, and usually have roller-piloted retainers.

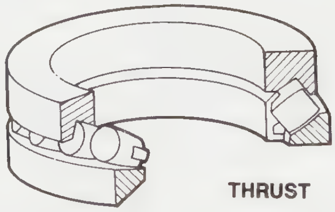
Another class of double-row bearings is the journal roller bearing, which usually has two nonlocating races. In some cases, the shaft is used as the inner race. When that is done, the shaft must be hardened and ground to tolerances equivalent to those of a bearing race.

Spherical bearings

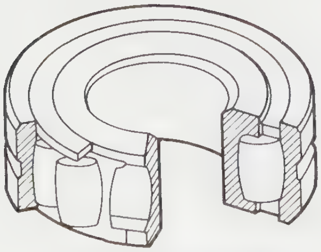
Spherical roller bearings offer an unequaled combination of high load capacity, high tolerance to shock loads, and self-aligning ability, but they are speed limited. Accordingly, they are used in vibrators, shakers, conveyors, speed reducers, transmissions, and other heavy machinery. Although the majority of spherical roller bearings are made to RBEC-1 tolerances, high-precision grades are available.

SPHERICAL-ROLLER BEARINGS

Thrust bearings have bore sizes from 3.3 to 14.2 in., and can tolerate up to 3° misalignment. Asymmetric rollers give about 50% more thrust capacity than symmetric rollers.

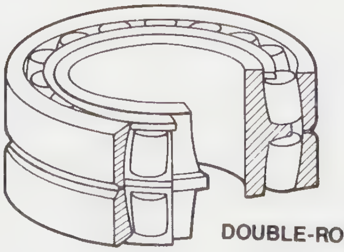


THRUST



SINGLE-ROW BARREL

These bearings have high radial, but low thrust, capacity. Bore sizes range from 0.78 to 12.6 in. They can tolerate misalignment up to 2°.



DOUBLE-ROW

Double-row bearings cover bore sizes from 1 to 49 in., and can tolerate misalignments up to 1°30'. Thrust capacity is a little less than one-third radial capacity.

Because load-carrying ability is so important, spherical roller bearings are available in a wide variety of radial thicknesses and axial widths. For a given bore size, double-row bearings are available in five different thicknesses and eight widths. The various combinations of width and thicknesses are designated by series numbers, which range from the very light duty series 39 to the very heavy-duty series 23. Depending on the bore size used for comparison, a series 23 bearing will have a capacity from 3.2 to 5.2 times that of a series 39 bearing.

Single-row barrel bearings have high radial but low thrust capacity. The rollers are symmetric, with modified line contact at both races.

Single-row thrust bearings are made with both symmetric and asymmetric rollers. Each has low radial and high-thrust capability.

Double-row convex bearings have high radial and moderate thrust capacity. Three types are coded by AFBMA. Type SLB is made with symmetric rollers. Rollers are guided by the pockets of a machined roller-piloted retainer, which is not quite as effective as guidance in the SC and SD types.

The SC design also has symmetric rollers, but rollers are guided by a floating guide ring. The retainer is usually a stamped assembly piloted on the inner ring. As in the SLB, there is modified line contact at both raceways.

The SD bearing uses asymmetric rollers, which reduce skewing tendencies, and keeps the rollers in contact with the center guide flanges. The overall result is better roller positioning, guidance, and better performance at high speeds.

Double-row concave bearings have characteristics similar to the double-row convex models, but are available in a much smaller range of sizes.

Tapered bearings

Tapered roller bearings are widely used in roll-neck applications in rolling mills, transmissions, gear reducers, geared shafting, steering mechanisms, and machine-tool spindles. Where speeds are low, grease lubrication suffices, but high speeds demand oil lubrication — and very high speeds demand special lubricating arrangements.

When a tapered bearing is subject to

Non-Friction Best Sellers.

Barden Precision Bearing Catalogs and Technical Bulletins

If you specify precision ball or linear bearings, these Barden publications should be on your "required reading" list. They answer questions about bearing design and selection; how cages, closures and lubricants affect running speeds, temperatures and load limits; identifying and correcting causes of bearing failure; proper handling and installation practices, and more.

To order, check the appropriate box next to the title and either fax or mail a copy of this page to:

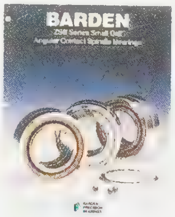
Barden c/o "Literature Request"
P.O. Box 2449, Danbury, CT 06813-2449
Fax number: (203) 744-3756

Product Engineering Catalogs

☐ **C-8B**
Condensed Precision Ball Bearing Catalog
24 pages

☐ **Cages**
Cage Designs and Materials for Ball Bearings
8 pages

☐ **Closures**
Seal and Shield Options for Ball Bearings
4 pages

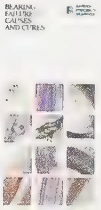


☐ **ZSB**
High Speed Machine Tool Spindle Bearings
22 pages

☐ **Flexlign**®
Self-Aligning Linear Ball Bearings
8 pages

☐ **L-1**
Linear Ball Bearings
12 pages

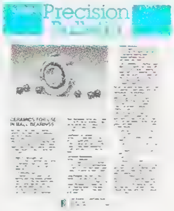
Technical Guides



☐ **Bearing Failure: Causes and Cures**
Identifying and Correcting 12 Causes
16 pages

☐ **Bearing In Mind: Precision Ball Bearing Basics**
Ball Bearing Design Considerations
16 pages

Precision Bulletin Series

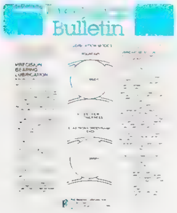


☐ 1
Ceramics For Use in Ball Bearings
1 page

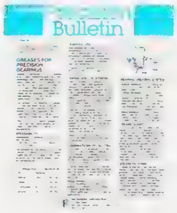
☐ 2
Ultra Precise Spindle Bearings
1 page

☐ 3
Coatings for Balls and Bearing Surfaces
1 page

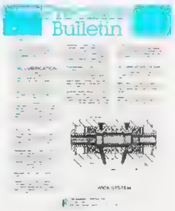
☐ 4
Improving Speedability in Ball Bearings
1 page



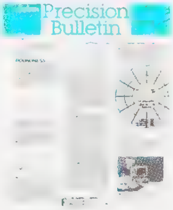
☐ 5A
Precision Bearing Lubrication
2 pages



☐ 5B
Greases for Precision Bearings
1 page

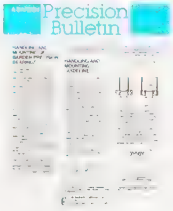


☐ 5C
Oil Lubrication
2 pages

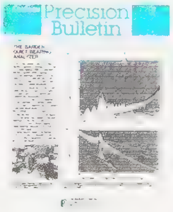


☐ 6A
Roundness
1 page

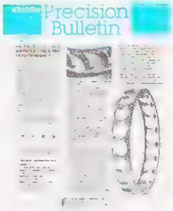
☐ 6B
Curvature Measurement
1 page



☐ 8
Handling and Mounting of Precision Bearings
2 pages



☐ 9
Quiet Bearing Analyzer
2 pages



☐ 10
Phenolic Cage
1 page

(Please fax or mail this page to address at lower right)

Name ____________________

Title ____________________

Company ____________________

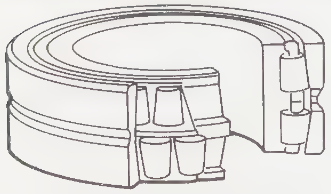
Address ____________________

____

Phone ____________________

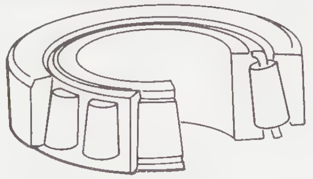
THE BARDEN CORPORATION
P.O. Box 2449
200 Park Avenue, Danbury, CT 06813-2449
(203) 744-2211 / FAX (203) 744-3756
(800) 243-1060

TAPERED-ROLLER BEARINGS



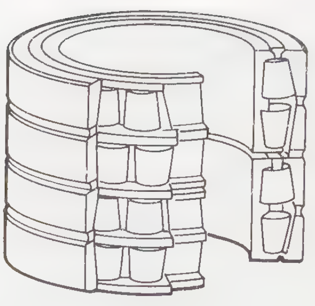
DOUBLE-ROW CONVEX

Double-row bearings have bore sizes from 0.3 to 59 in., and can replace two single-row bearings mounted back to back or face to face.



SINGLE-ROW

Single-row bearings come in a wide variety of subtypes and cover the bore range from 0.3 to 56.5 in. Variations include types of cups, cones, and tapered or straight bores.



FOUR-ROW

Four-row bearings replace two two-row bearings. They have bored diameters from 2 to 59 in. and are usually used for heavy loads or special mounting problems.

a load, a force develops between the roller and the cone back-face rib, because the load tries to squeeze the rollers out of the bearing. Most of the load is carried by normal forces at the cup-roller and cone-roller contacts, but a small force is always present at the roller-cone back-face rib contact. This contact also provides roller guidance, so careful design and precise machining of this surface and roller ends are required. Techniques for lubricating this roller-rib contact area permit high-speed operation of tapered bearings.

Single-row bearings are the most widely used tapered roller bearings. They have a high radial capacity and a thrust capacity about 60% of radial capacity. The exact percentage depends on size. Variations within the type include tapered bores for frequent removal, pin cages and hollow rollers for higher capacity, and steep roller angles for higher thrust capacity.

Two-row bearings can replace two single-row bearings mounted back-to-back or face-to-face when the required capacity exceeds that of a single-row bearing. If the bearing contact lines converge away from the bearing axis, the bearing is more tolerant to misalignment. If they converge toward the axis, the bearing has higher resistance to moment loading, but lower tolerance for misalignment.

Four-row bearings have characteristics similar to two two-row bearings mounted side-by-side. They are used to provide high capacity or to accommodate special mounting problems.

Needle bearings

Needle bearings are roller bearings with rollers that have high length-to-diameter ratios. They are used in farm and construction equipment, automotive transmissions, small gasoline engines, gear pumps, small appliance and tool motors, alternators, and aircraft controls.

Needle bearings are usually lubricated with grease, but oil or oil-mist lubrication is preferred for heavy-duty or high-speed applications. Many light-duty bearings never require relubrication, but high loads or speeds demand it.

Compared to other roller bearings, needle bearings have much smaller rollers for a given bore size. They have the highest load capacity for a given radial space of all rolling-element bearings, but their use is limited to bore diameters less than 10 in.

All the various types of needle bearings are variations of two basic designs. The first, full complement, has a full complement of needles, and contains no retainer. The second, caged needle, contains a retainer or cage for roller guidance and spacing. Caged bearings have smaller roller complements and lower load capacities than full-complement bearings. Their advantage is a higher speed capacity; retainers prevent high-velocity rubbing between adjacent needles, and provide more effective roller guidance. They also have greater lubricant capacity.

Loose-needle bearings are simply a full complement of needles in the annular space between two hardened machine components, which form the bearing raceways. They provide an effective and inexpensive bearing assembly with moderate speed capability, but they are sensitive to misalignment.

Caged assemblies are simply a roller complement with a retainer, placed between two hardened machine elements that act as raceways. Their speed capability is about three times higher than that of loose-needle bearings, but the smaller complement of needles reduces load capacity for the caged assemblies.

Drawn-cup, full-complement bearings consist of a deep-drawn cup (the outer race) with a full complement of needles. In some designs the needles are retained by the cup lips, in others they are retained by the grease. Spherical-ended, rather than trunnion-ended, rollers are used in the grease-retained bearings, which give a slight gain in load capacity.

Drawn-cup, caged bearings are dimensionally identical to full-complement bearings, except that a retainer is used. As usual, the retainer and reduced complement provide higher speeds and reduced load capacity. In addition, the caged bearing has somewhat better tolerance for misalignment than the full-complement bearing.

Heavy-duty bearings are made with relatively heavy outer rings, made from hardened and precision-ground materials. Their load capacity is high because of the retainer-guided end-relieved rollers.

Cam followers or track followers are heavy-duty needle bearings with either an integral stud or a nonseparable inner ring that accepts a yoke-mounting stud. The basic follower can include almost any combination of special features such as seals, self-lubricating rings, eccentric-mounted studs, crowned outer races, heavy-duty studs, and a variety of platings and coatings.

Aircraft bearings are heavy-duty compact assemblies that have maximum load capacity under static, oscillating, or slowly rotating conditions. The single-roller types have low tolerance to misalignment. Some double-roller types have a two-piece outer race that compensates for misalignment. All types are provided with grooves and oil holes for relubrication through the shaft or housing.

Thrust bearings are caged bearings with rollers assembled like the spokes

The Torrington Company. The broadest product line and the most advanced bearing technology in the world.

Fafnir Ball Bearings
Torrington Needle Bearings

Torrington Roller Bearings
Kilian Precision Machined Bearings

CALL TOLL-FREE 1-800-982-0030 (8:00 a.m. to 8:00 p.m. EST) for the name and number of the nearest Torrington district office and/or authorized Torrington Distributor.

TORRINGTON
Part of worldwide Ingersoll-Rand

of a wheel in a wafer-like retainer. These bearings can operate at fairly high speeds, despite some continuous slippage between the roller and raceway surfaces, which occurs because the rollers are cylindrical rather than tapered.

Selection factors

Generally, ball bearings are less expensive than roller bearings for small bores and light loads, whereas roller bearings are less expensive in the larger sizes and heavier loads. Roller bearings are more resistant than ball bearings to shock or impact loads, but lack some of their speed or misalignment capability.

Probable misalignments between housings and shafts suggest that self-aligning bearings are needed. At least make sure that the bearing can stand up to expected misalignments.

Ball thrust bearings should be subjected to only pure thrust loads. At high speeds, a deep-groove or angular-contact ball bearing is usually a better choice — even for pure thrust loads.

Ball bearings and cylindrical roller bearings have low friction coefficients.

Many different bearings are available with built-in seals for prelubrication. Some are lubed for life. Give special consideration to these types in consumer applications and applications where maintenance may be marginal.

Load rating

Basic dynamic load rating is the load at which 90% of a group of bearings can survive one million inner-race revolutions. However, some manufacturers use 90 million inner-race revolutions as the rating basis. In either case, basic load rating is the figure of merit used to evaluate bearing life in applications were fatigue — rather than inadequate lubrication, excessive temperature, overloading, or overspeeding — is the primary failure mechanism. Relationships for predicting bearing fatigue life under both constant and sinusoidally varying radial loads are given elsewhere in this chapter.

Relations for calculating basic dynamic load rating for conventional bearings are given in AFBMA Standards, in Sections 9 and 11. The calculated ratings tend to be low because of recent advances in bearing technology.

Basic static-load rating is the maximum radial or thrust load that a bearing can endure without excessive permanent deformation. Maximum deformation of a rolling element or race that does not significantly degrade bearing performance is 0.0001 times the diameter of the rolling element. Equations for basic static load for standard bearings are given in Sections 9 and 11 of the AFBMA Standards.

Bearing materials

Bearings materials are classified as through-hardened materials (used largely for ball bearings) and case-hardened materials (used largely for roller bearings). Critical applications require vacuum-processed steels.

Regardless of material type, a commonly accepted minimum hardness for bearing components is 58 R_c. Less hardness allows the races to Brinell. Since hardness decreases with increasing temperature, conventional bearing steels such as 440C and SAE 52100 cannot be used much above 350°F.

Through-hardened materials have received much attention in an effort to develop steels suitable for high-temperature bearings. Alloys with various proportions of molybdenum, tungsten, chromium, vanadium, aluminum, and silicon are used to produce hardness at high temperatures.

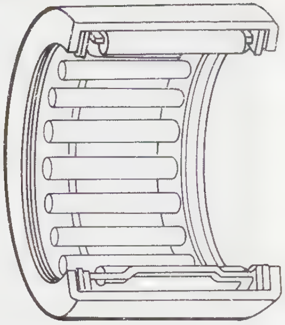
The ball-bearing industry has used SAE 52100 steel as a standard material since 1920. This is a high-carbon chromium steel which also contains small amounts of manganese and silicon. This air-melted alloy is clean, hard, and wear resistant.

For corrosive environments, 440C stainless steel should be considered. However, bearings made of 440C do not have as high a dynamic capacity as those made of SAE 52100.

Halmo and M-50 are usable up to about 600°F. M-50 is the more widely used. T-1 and M-10 are good to 800°F, M-1 and M-2 to 900°F, and WB-49 to 1,000°F. Oxidation resistances of M-1 and M-2 are marginal above 900°F.

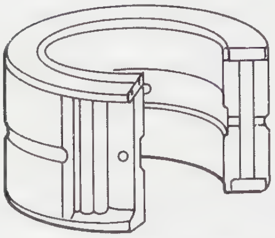
For M-50 and M-1 the dynamic capacity can be exceeded at 600°F, but dynamic capacity of bearings made of

NEEDLE-ROLLER BEARINGS



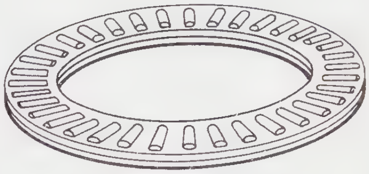
DRAWN-CUP CAGED

Drawn-cup roller caged roller bearings cover the bore range from 0.2 to 2.8 in. They have less static and dynamic load capacity, but a higher speed limit and increased tolerance to misalignment compared to full-complement bearings.



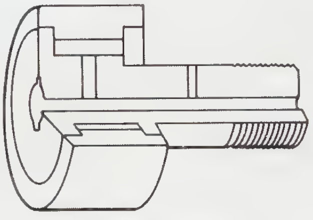
FULL-COMPLEMENT AIRCRAFT

Full-complement aircraft bearings have bore sizes up to 4 in. Other full-complement bearings have bores to 7.3 in. Both have high dynamic load capacity, moderate static capacity, and a moderate speed limit.



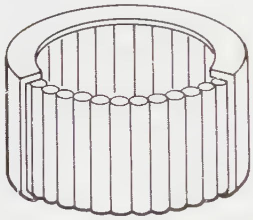
THRUST

Thrust bearings have bore diameters up to 4.1 in. Their static and dynamic load capacities are very high, but tolerance to misalignment is low.



CAM FOLLOWERS

In these bearings, the needles are retained by lips rolled over trunnion-ended rollers or by a grease pack. Sizes range from 0.125 to 7.25 in.



FULL-COMPLEMENT DRAWN-CUP

A heavy outer ring on these bearings carries high rolling loads. Bore sizes range from 0.5 to 6 in.

WB-49 should be derated above that temperature.

In addition to operating temperature, criteria for choosing a material should include fabrication costs. Generally, bearings made from M-series materials cost about 50% more than those made from SAE 52100, because of grinding difficulties. At temperatures below 350°F, there appears to be no technical advantage of M-series materials over SAE 52100.

Carburized, or case-hardened materials are characterized by a hardened surface (greater than 0.015 in. thick) and a soft core. At room temperatures, the surface hardness of these materials run around R_c 58 to 63, and their core hardnesses are R_c 25 to 48. These materials are generally limited to temperatures less than 350°F.

Two exceptions to the temperature rule are Timken CBS600 and CBS1000. If hot hardnesses of 58 R_c are required, CBS600 appears to be limited to 450°F, and CBS1000 to 600°F.

No data are available to compare the dynamic capacities of carburized and through-hardened materials. Where shock, and high vibrational loads are present, carburized materials may have an advantage because of their soft, ductile inner core.

Vacuum-melt steels provide increased reliability and basic dynamic load rating, because they have a lower inclusion content than air-melted steels. However, the improvement in bearing life is not always commensurate with the improvement in cleanliness. Nonmetallic inclusions are present to some degree even in exceptionally clean steels, and can be the nucleus of fatigue cracks.

Induction vacuum melting is a process in which a cold charge is melted in an induction furnace and then poured into ingots; the whole operation is performed in vacuum. Drawbacks of this process are high cost and variations in quality because of refractory problems.

A better way to make bearing steels is consumable-electrode vacuum melting. Electrodes made from air-melted heat are remelted under vacuum by electric arcs. The remelted product solidifies in a water-cooled copper mold under vacuum. This gives different solidification conditions than the induction-melting technique and produces a more consistent high-quality steel.

Manufacturing

Some manufacturing processes increase bearing life. Their main disadvantage is additional cost.

Forging produces a fiber orientation in the race material that makes the races less sensitive to variations in steel quality. Bearings with forged races can have dynamic capacities up to twice as high as bearings with races cut from tubing.

Compressive residual stress reduces maximum shearing stress and increases fatigue life. For bearings with light to medium loads, residual compressive stress can increase life. But for bearings with heavy loads, the effect is significant.

Controlled-hardness bearings have rolling elements and races that are matched for hardness. Generally, the rolling elements are 1 to 2 R_c harder than the races. Since fatigue life is related to hardness, the matching process can result in order-of-magnitude improvements in fatigue life.

Retainers or cages

The function of a retainer is to maintain proper distance between rolling elements. Almost all roller bearings have stamped retainers made of iron-silicon bronze or lead brass. Run-of-the-mill bearings tend to have stamped steel retainers.

DRIVEROLL™

ELECTRIC CONVEYOR ROLLER

Here's a major breakthrough in conveyor technology. A 1.90'' diameter conveyor roller with self-contained motor and transmission. Operating on safe, low voltage DC power, it's perfect for lifts, transfers, shuttles or any other powered roller application. Simply ''pop'' the hex shaft in your frame, connect a single wire and you're ready to drive. Call or fax for details.

INTERROLL®

Wilmington, NC • 919-799-1100 • Fax 919-392-3822
Paramount, CA • 310-633-0220 • Fax 310-633-0386
Aurora, ONT • 416-727-3399 • Fax 416-727-3299

Circle 288

Material properties

Type	Modulus of elasticity (10^6 psi)	Coefficient of expansion (10^6 in./in./F)	Density (lb/in.)
AISI 52100	30	7.0	0.283
AISI 440C	29	5.6	0.280
303 CRES	28	9.6	0.290
316 CRES	28	9.4	0.290
17-4PH	28.5	6.0	0.281
6061 Aluminum	10	13.0	0.098
Beryllium copper (C17200)	18.5	9.9	0.298
Titanium (Ti-6Al-4V)	16.5	5.3	0.160

Stamped bronze or brass retainers for ball bearings are used more in Europe than the U.S.; here, they are generally an extra-cost option for high-speed applications. Plastic retainers have higher speed capability than metal retainers in most applications, but are temperature limited.

Retainer wear is inversely related to hardness, so in general, the harder retainer materials are more desirable, particularly at high speeds. However, plastics such as phenolic are used at operating temperatures up to 270°F, PTFE to 450°F, and polyimide to 500°F. Common metals for low wear are S-Monel, M-1 and 440C. Common softer metals include cobalt and copper alloys.

For most applications, retainers can ride on the outer or inner race. But for high speeds, they should ride on the outer race and be thin enough to allow lubricant flow between retainer and inner race. For high-speed small-bore bearings, it is often necessary to use a silver-plated semihard tool-steel retainer with oil-mist lubrication.

Specialty bearings

Specialty bearings appear in many shapes and sizes. Many of the considerations for selection and application of these bearings are the same as those previously discussed for rolling-element bearings.

Rolling-element instrument bearings

Rolling-element instrument bearings are precision bearings that include at least one of the following characteristics

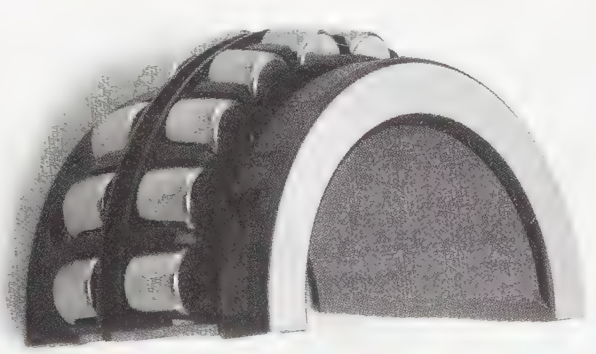
- Smooth running or limited vibration.
- Low or uniform operating torque.
- Control of contact angle or preload levels.
- Extreme applications.

Typical applications are in gyro motors, gyro gimbals, synchros, servomotors, gearheads, differentials and speed reducers, data encoders, potentiometers, tape guides and idlers, tape capstans, and flowmeters.

Most applications require the lowest possible operating torque. Thus, instrument bearings generally have lightweight retainers and open race curvatures for minimum contact area.

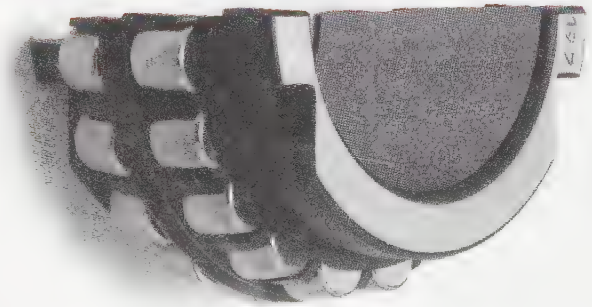
Unlike other bearings, they usually do not fail from metal fatigue caused by dynamic operating loads. Instead, failure is represented by some level of operating torque that affects instrument performance. Torque increases are generally traceable to contamination or lubricant breakdown. In the worst case, the retainer is destroyed or jammed because of excessive contamination or wear particles.

The bearings generally do not have a continuous supply of fresh lubricant.



The Split Spherical Roller Bearing. Exclusively from FAG. Designed to get you out of tight spots. Like when equipment is down and costs are climbing. Because of its unique patented design, the Split Spherical Roller Bearing cuts change-over time in half. And makes replacement easy for critical applications with restricted access. Get the facts in the Split Spherical Roller Bearing Design Guide. For technical information call 800-243-7512. For literature call 516-243-4567 or FAX 516-243-0508.

NOTHING ELSE WILL GET YOU INTO THE TIGHTEST SPOTS, OR OUT OF THEM.



FAG

FAG Bearings Corporation

911 Hope Street
P.O. Box 4915
Stamford, CT 06907-0915

Circle 289

This condition is unavoidable and imposes a severe limitation on life.

Precision instrument bearings are available in three tolerances levels — ABEC 5P and 5T, 7P and 7T, and 9P. A semiprecision grade is also available which meets ABEC 3 tolerances without the extra performance requirements mentioned above.

Instrument bearings are divided into three basic size ranges:

Miniature: Bearings with an OD less than 0.375 in. and certain thin-section bearings with a maximum OD of 0.500 in.

Intermediate: Consist of inch or R-series bearings and the metric or 30-series bearings, which range in size up to 1-in. OD.

Thin-section and torque-tube: Bearings available in sizes up to 4.000-in. OD. (A variation is the extrathin-section series that have a bore-to-OD section of 0.125 in. for all sizes up to 1.875-in. OD.)

Speed

Limiting speed values for instrument bearings are almost impossible to determine. However, generalizations may be made.

Bearing size: Highest speeds may be obtained with the smallest bearing. However, extremely small miniature bearings usually have a thin, weak retainer, and their maximum speed is less than medium-size miniatures.

Load: Limiting speed is directly affected by the magnitude of applied load. Heavy loads result in a decreased speed capability. Use of a preloaded pair of bearings also decreases allowable speed.

Ring rotation: Inner-ring rotation gives higher speed capability. If the outer ring is rotating, limiting speed must be reduced by about one-third.

Retainer: Phenolic (and some other nonmetallic materials) — very high speed; crown (hardened steel) — high speed; ribbon (loosely clinched) — low speed; full race — moderate speed; spacers (PTFE) — very low speed.

Lubricant: Stiff, mineral-oil grease — high speeds; soft, synthetic-oil grease — moderate to high speeds; soft, silicone grease — low to moderate speeds; mineral oil — high speeds; synthetic oil — moderate speeds; silicone oil — low speeds.

Lubricant method: Oil impregnation and grease pack — excellent; oil impregnation — very good; grease pack — good; minimum oil — fair.

Loads

In some applications, allowable load seriously influence selection. Major variables affecting load capacity are ball size and number, and internal geometry of the bearing.

Static: Primary consideration is given to static ratings. A bearing may be deformed permanently by high loads on nonrotating bearings, or severe instantaneous loads on rotating bearings.

Radial static capacity for instrument bearings is defined as the load causing a permanent, plastic deformation of 0.0001 in. of the ball diameter at the ball-raceway contact. This deformation degrades the smoothness and noise level of the bearing. However, in less critical applications, higher loads can be accommodated.

Static thrust-load rating is based on two considerations: 1. Load at which the ball-raceway stress approximates that calculated for the heaviest-loaded ball under the limiting static radial load. 2. Load that causes the contact area between the ball and raceway, to climb over the edge of the raceway shoulder.

Dynamic: Dynamic load ratings are not directly applicable to life prediction of instrument bearings because little life-test data is available. However, metal-fatigue failure is seldom encountered in instrument applications.

Recommended use of dynamic load ratings for instrument bearings is limited to a comparison of relative capacity for different sizes or designs. Dynamic load capacity also may be used as a general guideline for the magnitude of operating bearing loads. A rule of thumb is: light loads, 0 to 5% of C factor; moderate loads, 5 to 15% of C factor; heavy loads, over 15% of C factor.

Not all manufacturers use the same load calculation methods. Thus, selection of a bearing because of a high advertised load rating is not recommended. The comparison for load-carrying ability should be based on the same formula. If a formula is not available, a fast, accurate comparison can be made by determining Nd_2 values for each bearing (N = number of balls; d = ball diameter). The higher the Nd_2 value, the higher the load capacity for bearings of similar design and material.

Deflection

Bearing deflection or yield is elastic deformation occurring between balls and raceways because of external loads. Deflection increases nonlinearly as external load increases.

To increase bearing stiffness (lower deflection rate) the factors to adjust are:

Contact angle — increase.

Race curvature — decrease or close up.

Ball size — increase.

Ball complement — increase.

For a low-contact-angle bearing, axial deflection per unit load is considerably higher than radial deflection per unit load. For most applications, radial yield rate is neglected and principal attention is given to axial loading and deflection.

Minimizing deflection: Contact-angle control has the largest influence on the yield rate and is also the easiest to adjust. Race curvature can also be adjusted, but with more difficulty. At higher contact angles, the influence of curvature on deflection becomes less significant.

Preloading: Bearings are preloaded to eliminate high initial deflections and to achieve a constant (linear) deflection rate. Preloading is achieved by mounting two bearings in opposition to provide an internal load within the bearing.

The magnitude of this internal load is controlled by matching stickouts of each bearing or flush grinding of the rings under specified preload. Either the radial retainer or the angular-contact type of instrument bearing can be supplied as preloaded or duplex pairs.

Preloading bearings in either a back-to-back (DB) or face-to-face (DF) mounting arrangement allows for: precise control of axial deflection rates; accurate positioning of the shaft relative to the housing; and increased radial load capacity. The DB mount is most common and provides high resistance

Guide for CAM followers

Type of application	Standard	Sealed	Eccentric stud	Self lubricating	Crowned	Heavy stud
Standard	X	X	X	X	X	X
Contaminated		X		X		
Misaligned				X	X	
Shock or heavy loads						X
Load Sharing			X			
Long Life		X		X		
Circular tracks					X	

to overturning moments. The DF mount has less resistance to moment loads, but is less sensitive to slight misalignments.

Design of a preloaded bearing pair for a specific application is based on maximum allowable axial-deflection rate and maximum applied external thrust.

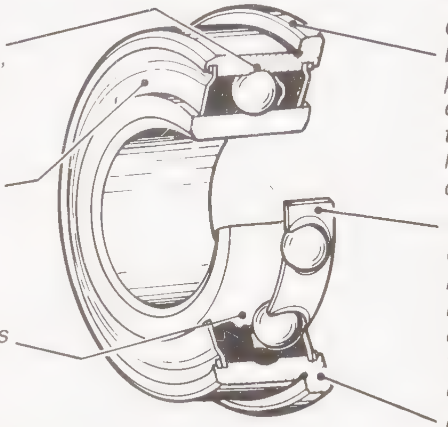
Deflection rate of the preloaded pair is a function of the single-bearing characteristics, but can be altered by adjusting the preload level.

For proper operation, the unloading point of the preloaded pair must be greater than the maximum external thrust load. Value of the unloading point is determined principally by preload level and, to a lesser degree, by the single-bearing characteristics. As a general guideline, the unloading point is approximately three times preload level; however, exact determination must be made from the deflection curves.

SPECIAL BEARINGS

Special bearings are designed with nonstandard configurations or materials primarily to provide greater precision; extend service life; provide liberal safety margins for severe loads; or to ease assembly, maintenance, or repair. These benefits can easily outweigh the high initial cost.

Virtually any feature of a bearing can be changed to make it special. Some of these changes are modest, such as a minor variation in retainer design or the specification of a nonstandard lubricant. Other modifications are more pronounced, such as the design of special integral shaft-bearing assemblies made of high-strength tool steels or nonmagnetic beryllium-copper alloys. Bearing ratings, package envelope, and operating environment determine how "special" a bearing must be.



TOLERANCES
Special tolerances can be specified to control noise, vibration, frictional torque, accuracy, radial runout and bearing life. Tighter tolerances increase cost.

SEALS OR SHIELDS
Variations in sealing or shielding can influence bearing speed, torque, lubricant retention, and friction.

LUBRICANTS
Special lubricants reduce friction and improve bearing life. Improper lubricants can limit operating speed and decrease accuracy.

TESTING
Special tests may be specified to assure specific levels of quality, performance, and predictability. Manufacturers commonly test for torque, speed limitations, noise, vibration, life, and deflection.

MATERIAL
Changes in material determine bearing cost and influence performance in extreme environments. Contamination, temperature, corrosion, magnetism, load capacity, and operating speed can prompt a material change.

RETAINER
Changes in retainers can increase bearing operating speed and life, reduce need for lubrication, and decrease frictional torque and vibration. Retainer modifications increase cost.

CONFIGURATION
Variations in bearing size, shape and functional features can be provided by special configurations.

The performance for a bearing usually can be defined by five basic parameters: rotational freedom, position control, operating speed, operating temperatures, and vibration and noise. With the specification of these parameters, the bearing design requirements begin to take shape.

Standard bearings sometimes can fall short of requirements by not meeting package envelope limitations in terms of size, weight, and accuracy. Generally, the more liberal the constraints for size and weight, the more reliable and sophisticated a bearing system can be. Often, space and weight can be saved if races are made integral with shafts, housings, or both. Also, nonstandard dimensions or special configurations can be specified to overcome physical restrictions.

High temperatures, cryogenic temperatures, corrosion, vacuum, or high radiation fields all must be carefully considered because they will affect the bearing's final design. Special greases and oils may be needed for temperatures below −110 and above 500°F. Also, custom configurations or nonstandard seal materials may be needed to keep out contaminants or to retain lubricants.

Lubrication

Instrument bearings can be lubricated with oil, grease, or dry films.

Oils: Synthetics are used most widely for instrument bearings. Petroleums also are used for their excellent lubrication properties under heavy load and high-speed conditions.

Silicones are not true oils, but are listed as such for convenience. Principal advantages are excellent viscosity-temperature characteristics, good resistance to oxidation, and wide operating-temperature range.

Standard method for applying oil lubrication is to dip the bearing in the oil, remove, and centrifuge excess oil from the bearing.

For extremely critical torque applications, oil quantity can be reduced to a minimum by centrifuging at high levels (200 to 500 g) for extended periods of time (2 to 10 min). However, reduction in oil quantity can have substantial effects on bearing life and its use should be carefully considered. For instrument bearings with phenolic, sintered nylon, or porous polyimide retainers, oil is impregnated into the retainer to provide a constant source of lubrication during operation.

Greases: Grease lubrication is usually chosen for moderate to high speeds and light to heavy loads. Often the high-speed torque of a grease-lubricated bearing will be lower than for an oil-lubricated bearing. However, the slow-speed running torque for grease-lubricated bearings is about 15 to 40 times that of oil-lubricated bearings. Specific torque values depend upon the type and quantity of grease.

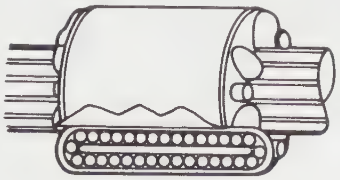
Standard method of grease application is the grease pack. The bearing is loaded to about one-third full. Other fill quantities can be supplied, if required.

A unique process of applying a thin film of grease to all bearing surfaces is by grease plating. The bearing is coated with a mixture of grease and solvents. The solvent is removed by heating,

SHAFT LINEAR BEARINGS

Ball spline: Although more commonly used to transmit torque, ball splines can be used as efficient linear-motion bearings. They resemble linear ball bearings and have the same type of motion. The balls roll in grooves in the outer race as well as in grooves on the shaft and, thus, resist torsional moments.

Ball splines may be used where only one shaft is practical and where the load is applied at a considerable distance to one side. The torque load applied determines the side-load moment. In this type of application, accelerating forces and inertia apply a cocking effect that must be taken into account. When used with a side load, ball splines have a considerably higher load capacity than linear ball bearings, but cost more.

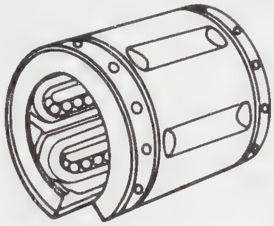


Linear ball bearing: A recirculating type of shaft bearing. The balls circulate in a number of loops in the cylindrical bearing body which surrounds the shaft. Some types are split longitudinally so that the bearing can be adjusted to eliminate clearance.

Little force is required to produce relative motion between these bearings and a shaft. Coefficients of friction are 0.001 to 0.004, comparing favorably with radial ball bearings. These bearings are sensitive to torsional moments and should be used in pairs. If they are used on parallel shafts, one shaft should be "floated" to prevent excessive loading from misalignment.

The slot normally is located 90° to the direction of the load. For an unusually long shaft, an open design is used, where a longitudinal section, usually equal to one ball circuit, is removed to permit use of shaft-support members.

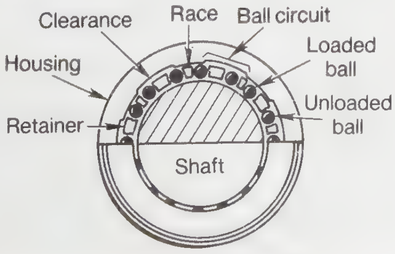
Special designs are used to minimize wear. In one, the ball-roller-retainer assembly is rotated during linear motion to expose each ball circuit to a new running path. This prevents tracking or grooving of the shaft or housing. Another type contains a compliant bearing plate that deflects under load. This compliance lowers unit contact stress between the balls and plate. Longitudinal taper of the bearing plate provides self-alignment. In still another variation, the balls and tracks are arranged in such a way that the bearing can rotate as well as translate.



Caged bushing: Provide both linear and rotary motion. An array of nonrecirculating balls is contained in the ball-retaining cage. As in ladder-type bearings, extra length of one-half stroke is required, because the balls do not circulate. Other units are designed for rotary motion only.

Linear rotary bearing: The linear rotary bearing accommodates both linear and rotary motion, either independently or simultaneously, with greater load-life ratings than those of conventional linear bearings. The bearing has multiple oval-shaped ball circuits that are separated by a retainer. The retainer allows both sides of each ball circuit to contact the shaft, but not at the same time.

An alternating race and clearance on the inside of the housing permits only the balls on one side of each circuit to contact the shaft and carry load, while the balls on the opposite side of each circuit recirculate. The bearing allows simultaneous linear and rotary motion because balls can rotate in any direction and the retainer can rotate within the housing.



leaving a thin film of grease on all surfaces. Although there are limitations to this method, plating gives lower torque than a grease pack and retains the lubricant on bearing surfaces better than oil lubrication.

Dry-film lubricants: Lubrication by dry film has not been successful in instrument bearings, and should be attempted where conditions prohibit any other type of lubricant. Principal problems encountered are proper treatment of the surface material, control of film thickness, and wear products which are normally generated during bearing operation. These wear products contaminate the bearing. Nominal film thickness normally required for instrument bearings is on the order of 0.0001 to 0.0003 in., with variations not exceeding 5 to 10 μin.

Torque

Bearing torque is the moment required to overcome internal friction to start or maintain rotation of one ring while the other is stationary.

Torque or friction generally increases when: 1. Bearing size is increased because a larger ball and retainer must be moved. 2. Load is increased because of greater deformation and resistance to rolling motion. 3. Speed is increased because of increased lubricant drag.

Lubrication type is a critical torque factor. Oil-lubricated bearings generally have lower low-speed torque than grease-lubricated bearings. However, grease-lubricated ones may have lower torque at high speeds, particularly if a channeling grease is used. High-viscosity oils have a higher torque than low-viscosity ones.

Bearing design also influences torque. Lightweight metal and molded plastic retainers have the least torque for low and moderate speeds. Phenolic and sintered nylon retainers have lower torque at high speed. Very low contact-angle or radial-play values show high torque because inherent geometrical errors in the bearing raceway and balls cause erratic variation in stress and, hence, friction level. Very high contact angles have higher torque levels because of the sliding motion in the ball-to-race contact area.

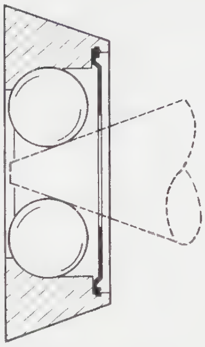
Torque-test levels vary from manufacturer to manufacturer, and even lot-to-lot for one manufacturer. There are three types of bearing torque ratings, all based on testing under light loads with oil lubrication.

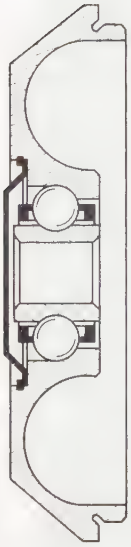
Starting torque: Restraining torque that must be overcome to start rotation of one ring of the bearing while

INSTRUMENT AND GUIDE BEARINGS

PIVOT

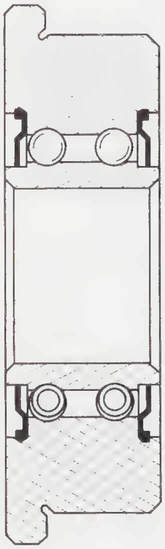
Accepts a coned-end gimbal shaft as its inner race. This full-complement ball assembly is made of SAE 52100 chrome steel. The bearing is designed for minimum starting frictional torque, with minimum free radial and end play. The bearing can withstand only light thrust loads. Often, this configuration is used instead of jewel pivots in instruments that must support shock loads.





END CAP

Increases accuracy, rigidity, and tolerance control. This semi-integral assembly has a single shield, nonseparable relieved outer ring, and SAE 52100 chrome steel rings and balls. The phenolic retainer is vacuum-impregnated with oil. Lubricant quantity is minimized to reduce torque variations. This assembly, used in gyro applications, is manufactured to ABEC 7P tolerances.

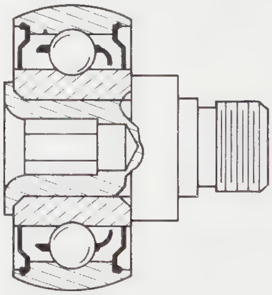


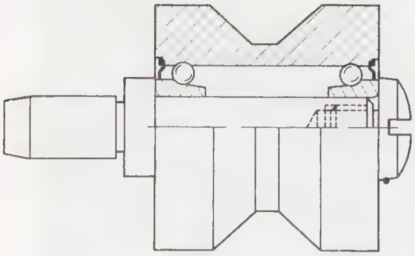
DOUBLE-ROW

Provides, moment stability, controlled axial play, and minimum starting torque. This bearing, with double shields, Teflon-tube ball separators, and light-oil lubrication, is manufactured to ABEC 5P tolerances.

STUDDED

Functions as a guide assembly in computer peripheral equipment. Its integral construction eliminates assembly of individual components. The shaft is made of chrome-plated, low-carbon steel. Bearing rings and balls are made of AISI 440C stainless steel. This bearing, with one-piece stainless-steel crown retainer, dual shields, and grease lubrication, is manufactured to ABEC 1 tolerances.



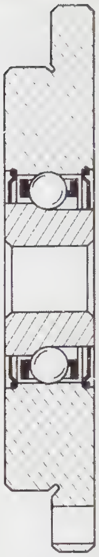


STUDDED-GROOVED

Functions as a guide assembly in cable or belt drive systems. The shaft is made of Series 300 stainless steel. The double-row bearing, a full-complement design with double shields and grease lubrication, is manufactured to ABEC 7P tolerances with minimum end play.

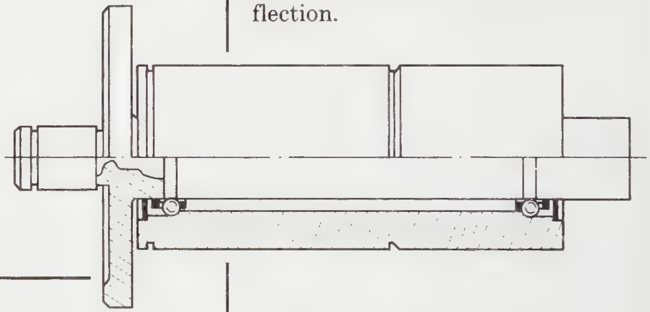
FLANGED

Bearing has a separable inner ring, double shields, TCP-treated SAE 52100 chrome steel rings and balls, and an oil-vacuum-impregnated phenolic retainer with supplemental grease. It is manufactured to ABEC 7P tolerances, with a controlled contact angle. Provides convenient mounting.



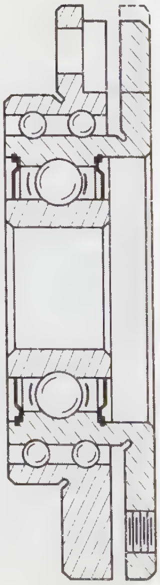
INTEGRAL SHAFT-HOUSING

Controls radial runout, tolerances, and shaft positioning. This disc pack drive spindle is used in random-access memory-storage systems. High spindle rigidity minimizes shaft deflection.



COAXIAL

Designed for minimum starting frictional torque, with minimum free radial and end play. This gyro gimbal bearing, with SAE 52100 chrome steel rings and balls, is manufactured to ABEC 7P tolerances with special mounting flanges. The coaxial design has a double-row outer bearing with Teflon-tube ball separators and a single-row inner bearing with a two-piece, ribbon retainer optimized for low frictional torque.

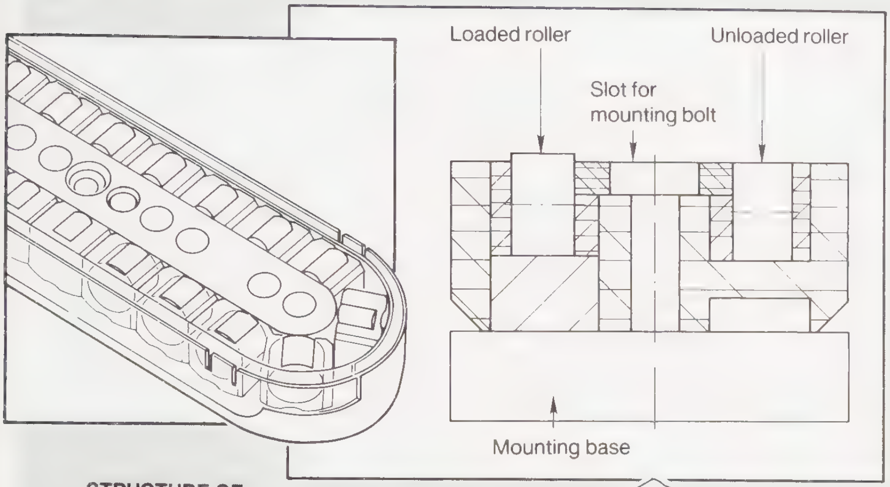


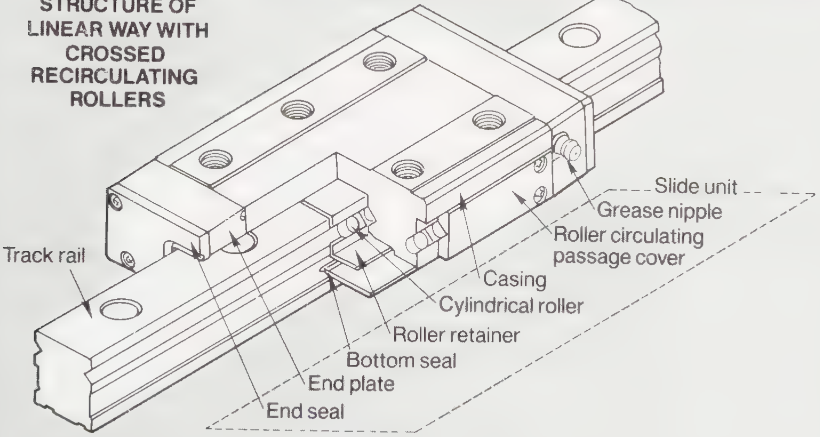
FLAT-WAY LINEAR BEARINGS

Recirculating roller bearing: A flat-way bearing that overcomes the travel limitation of ladder-type bearings by using the principle of recirculation. The illustration is simplified to show only roller motion. Actually, the bearing consists of a self-contained cartridge containing a channel through which the rollers rotate. After engaging the way, the rollers move into an end cap and upward into a return passage, where they roll forward to again come into position to engage the way.

In the most common types, the rollers are not perfectly cylindrical but are necked down slightly at the center to accommodate a guide rail which minimizes roller skewing, formerly a major problem with this type of bearing.

Recirculating roller bearings have higher load capacity than ball-type bearings because line contact sustains higher loads than the point contact provided by ball bearings. They also can resist substantial shock loads.




STRUCTURE OF LINEAR WAY WITH CROSSED RECIRCULATING ROLLERS

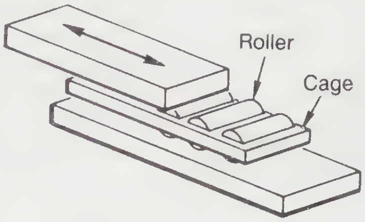
Deviation from squareness between bearing and way, or lack of parallelism to the line of motion, increases chances of roller skewing. Parallelism for banded roller way bearings is kept to within 0.0004 to 0.001 in./in., producing a tracking accuracy of 0.0005 in./in. of travel and less. Maintaining squareness is simplified by use of backup plate, which is pivot-mounted to compensate for nonuniform loads and machine deflections.

Maximum bearing stiffness is high and can be attained by relatively light preloading with a gib or screw adjustment. Bearings can also be mounted at 90° to the way to minimize side motion and deflection.

Cross-roll bearing: Another style of nonrecirculating flat bearings places alternating rollers 90° to the roller ahead or behind it. Without additional bearings, this technique handles loads not exactly perpendicular to the travel direction.

Ladder bearing: A nonrecirculating type of flat-way bearing, ladder bearings are often compared to roller bearings that have been "cut and stretched flat." The load rides on a series of rollers confined in a cage.

They are commonly used in a V-way on one side of a machine bed with a set of rollers running on a horizontal flat way on the other side. This arrangement compensates for expansion or contraction between the carriage and bed, and minimizes the need for parallelism between two widely separated ways. In some installations, the rolling elements are carried in a flexible cage similar to a roller chain. Elements not under the load hang over the ends of the bed and feed in as needed.

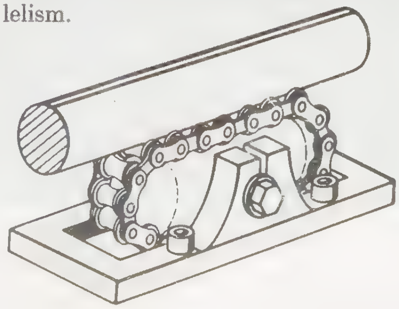


Balls have been used in similar bearings with mating V-grooved ways. However, larger balls must be used to move the same load.

Recirculating roller-chain bearing: The rollers are mounted in chain links which serve the purpose of a cage or spacer. For flat ways, the rollers are cylindrical; for shafts, the rollers have a conforming concave surface.

These bearings are self-aligning and have good load capacity for their size. They are sensitive to side loads, and a single bearing must be used in combination with V-mounted bearings or their equivalent. Coefficient of friction is 0.005 to 0.007. Bearings for round-shaft ways are available as single bearings with or without a mounting block, and as dual bearings in a V-block.

Preloading is provided by adjusting the eccentric trunnion pins. If preloading is done across a single master shaft, the secondary shaft need not be perfectly parallel. But, if preloading is done across two shafts, preload consistency depends on shaft parallelism.



the other remains stationary. Useful for applications involving oscillation, such as in synchros or gyro gimbals.

Average running torque: Mean torque encountered during slow-speed rotation on the running-torque tester. Useful where rotation is continuous and sudden fluctuations can be ignored, such as in servomotors or gear trains.

Peak running torque: Maximum torque encountered during slow-speed rotation on the running-torque tester. Peak running torque values are difficult to correlate to operating conditions. However, they do provide a measure of quality and consistency for a group of bearings.

Mounting

For instrument bearings, certain special considerations should be emphasized: 1. Heavy press fits should be avoided. 2. Accuracy of mounting surfaces should be equal to accuracy of mating bearing surface. 3. Misalignment for low torque and running accuracy should not exceed ¼°. Loading across the bearing during assembly should be avoided.

Axial positioning: Accurate axial positioning of the shaft relative to the housing requires shoulders, snap rings, or bearing flanges.

Shaft and housing shoulders: Diameter of a shaft or housing shoulder must be sufficient to ensure solid seating and support for applied thrust loads, yet small enough to avoid interference with other parts of the bearing. Most manufacturers provide recommended shoulder dimensions for each bearing size. Fit accuracy between shoulder and mounting diameter should be as good as bearing accuracy.

The corner between the shoulder and mounting diameter should be undercut because undercutting provides a more accurate machining of the shoulder surface. However, a radius is permissible if proper clearance is allowed.

Retaining rings: Certain cautions must be observed with this method: 1. Recommendations as to the groove dimensions should be followed. 2. Locating grooves machined into the shaft or housing must be controlled for squareness of groove face to bearing mounting diameter. (Recommended value is 0.0002-in. TIR max). 3. Parallelism of the faces of the ring should be held to 0.0002-in. TIR max. 4. Lug dimensions should be checked to ensure there is no interference with the bearing. (Extended inner-ring bearings may offer an advantage here.) 5. Avoid a snap ring that locates directly on the shaft or housing diameter (no groove) if heavy thrust loads are involved.

Flanges: Squareness of face-to-bore of the housing is critical and should be maintained to within 0.0003-in. TIR. Corners may be broken or left sharp, since the flange is undercut and flush seating is ensured.

Axial adjustment: Removal of excess bearing end play, when required, may involve preloading of the bearings. However, the most common requirement is to establish an allowable range of end play under a given reversing thrust load.

Shims: Best material is stainless steel. Brass shims can also be used; however, they wear more easily and produce abrasive particles that could contaminate the bearing. Shims, particularly brass or other soft materials, should be used only against the nonrotating ring.

Spring washers: Belleville and wave washers are the two most common types used. The washer should exert a very light load on the bearings. If extreme rigidity under external load is required, preloaded bearings should be used.

The use of a spring washer usually involves a loose fit between the bearing ring and its mounting surface. Therefore, the washer should apply its force against the nonrotating ring.

Threads: Generally, threads are not recommended to remove end play. They are too easily overtightened and can cause brinelling in the bearings.

If threads must be used, the bearings should be locked against a solid shoulder or spacer. It is important to achieve a solid locking force without overloading the bearing rings. A Class 2 fit is normally recommended because it provides for slight misalignment of the nut, enabling the nut face to be flush with the bearing. The nut-face squareness to the thread pitch circle should be held to 0.0005-in. max wherever possible.

Bearing fits: Extreme fits, whether loose or tight, are not recommended. The effect of press fits on contact angle or radial play must be considered. As a rule of thumb, mounted radial play (and hence contact angle) will be reduced by approximately 75% of the press fit. This is important where precise control on deflection rates is required or where low-radial-play bearings are used.

Size tolerance of the shaft and housing should be equal to those of the bearing bore and OD. Roundness and taper should be held to one-half of size tolerance. Surface finish should be held as close as possible.

Extreme fits will depend upon tolerances on the bearings, the shaft, and the housing. Upon request, the bearing manufacturer will code the bearing bores and OD into increments within the size tolerance. These increments are normally 0.0001 in., but can be supplied as low as 0.000050 in.

When operating at a temperature considerably different from room temperature, material expansion differences must be considered.

Adhesives offer several advantages in producing proper fits: 1. End play can be removed by applying a light external thrust load during curing time. 2. Extreme fits can be eliminated, since the adhesive will fill up any reasonable clearance. 3. Rotational accuracy can be improved by driving the shaft at slow speed during cure time.

Disadvantages to using adhesives include: 1. Certain adhesives are attacked by lubricants or solvents. 2. To ensure a good bond, bearing surface, shaft, and housing must be thoroughly clean of oil and dirt. 3. Adhesives may get into the bearing and cause damage. 4. To ensure a good bond without rotational inaccuracies, clearance should be held reasonably close. The tolerances on the shaft and housing should be of the same magnitude as standard-fits practice. Actual clearance depends upon the specific adhesive. 5. Under vibration, some adhesives may break loose.

Rolling-element linear-motion bearings

Linear-motion bearings deal with the problem of providing low-friction translational (rather than rotational) motion. Sliding-surface bearings are stiffer and deflect less under load than rolling-element types, and sliding-surface bearings allow greater load capacity per unit of surface area. But they also exhibit appreciable stick-slip, or a sudden surge of "breaking loose" when motion begins. Stick-slip results from a large difference between static and kinetic friction. Hydrostatic bearings do not have stick-slip, but they are complex and expensive.

Rolling-element linear bearings are simple and inexpensive, and they do not exhibit significant stick-slip because their static and kinetic friction is nearly the same. (Coefficients range from about 0.002 to 0.005.) These bearings, therefore, are preferred for precision machinery. They require less power to put a machine in motion. This factor is especially important in servo control where cost increases greatly as power requirements increase.

Linear bearings are of two types.

Flat-way bearings are designed to bear against flat surfaces. Shaft bearings are designed to ride along a round shaft.

Limits of travel

Linear rolling-element bearings are either of the recirculating or nonrecirculating variety. In the recirculating type, bearings roll around a track with an action akin to that of a radial roller bearing with a flattened inner race. Travel is limited only by the length of the ways. In the nonrecirculating type, travel is limited by the fact that moving surface cannot be allowed to roll off the roller train. The kinematics of this geometry is such that the rollers move only half as far as the load moves, so the way or shaft must be 50% longer than the distance traveled by the load.

Design considerations:

Load capacity: Hardness, finish, and conformity of race and rolling elements determine load capacity, which varies as the fourth power of the race Brinell hardness number. The surface finish must be smooth because grinding marks create ridges that prevent conformity between the race and the rolling element.

With a flat race, balls have lower load capacity than rollers, and large-diameter balls have to be used to carry the same load. If the mating way is ground with either a Gothic arch or circular groove, the closer conformity to the ball allows the use of smaller balls than with flat ways. The Gothic arch approximates a V-type way with the load effectively split at angles of about 45° with the vertical into two loads on the way. The circular groove has a higher load capacity, but the ball bears on the bottom of the groove, which results in side play under loads normal to the line of motion.

Preloading: Every rolling-element linear-motion bearing has some deflection between race and rolling elements. This deflection can be minimized by preloading, but this requires greater bearing accuracy and more careful installation. Preloading also increases drag friction and can be a drawback in servosystems where additional friction might require a larger servomotor.

When the operating speed approaches one of the natural frequencies of the bearing, vibrations can be set up. Rolling element bearings do not have natural damping. However, additional preloading can damp vibrations if drag friction is not a problem.

Life ratings: Manufacturers' data on life ratings generally give fatigue life based on data previously collected for ball bearings. These ratings are not always accurate for a linear-motion bearing. Recirculating flat-way roller bearings, for example, sometimes fail from skewing rather than from fatigue. Recirculating roller bearings, however, generally fail from fatigue and have a significantly longer life than other types of linear-motion bearings within their lower load limits.

Cleanliness: As with any type of bearing, precautions are recommended to exclude foreign matter, such as chips, grit, plastic dust, fibers, or other airborne material. Hard chips in the path of the balls cause ball spalling or fracture and can damage the races. Any dirt or grit between race and rolling elements produces wear, and the balls or rollers suffer progressive lapping that results in increased play. Plastic dust and fibers are particularly bad in recirculating bearings because the material tends to pack into the recirculating channels, and eventually prevents movement of the balls or rollers.

Bellows-type enclosures are best for keeping foreign material away from critical parts of the bearings. Telescoping tubes or cover plates also can be used to protect critical elements.

Some linear-motion bearings have integral rubber-lip seals that avoid the need for extended housings (to accommodate outboard seals) and which also simplify seal retention.

For round bearings, a clock-spring arrangement is sometimes used — the inner coil is attached to the end of the shaft and the outer coil is attached to the OD of the bearing. Some machine tool installations use a window-shade arrangement with way-covering material of heavy rubber or synthetic material that is stored on a roller arrangement at the ends of the bed.

If none of these methods are feasible, wipers or scrapers should be used. These are commercially available for flat or round surfaces, and are made of felt, leather, or plastic with spring-loaded fingers for positive sealing. Enclosures for ball splines are usually custom designed and are generally more effective at keeping out large chips than dust.

Lubrication: For low-friction operation, a thin film of oil keeps surfaces lubricated. The oil also inhibits rust, which causes problems. If the atmosphere is particularly corrosive, stainless steel or some other special alloy must be used as the bearing material. Surface coating and plating are not recommended. Unusual temperatures are not really a problem, but special high-temperature or low-temperature lubricants are available.

Unground ball bearings

Unground ball bearings may be wholly unground, ground in part, or wholly ground, but are characterized by precision levels less than ABEC 1. They are available in the traditional ball bearing forms to accommodate radial, thrust, and combined radial-thrust loads.

Materials: Low-carbon steels are employed widely; they are carburized and hardened to obtain enough wear resistance for good service under normal conditions. Certain applications require the corrosion resistance of stainless-steel or plated surfaces. In low noise applications, a variety of elastomeric compounds are molded or bonded to the outside diameters.

Tolerances: A proportion of 10:1 is reasonably close when comparing the tolerances on an unground bearing to those of a precision bearing. Thus, where 0.0005 in. might be specified for a ground bore, 0.005 in. is the norm for an unground bore.

Ratings: Failure in unground bearings is usually caused by wear, as compared to metal fatigue in precision bearings. Therefore, unground bearings do not exhibit the uniform statistical life tests results common to precision bearings. In the less-than-ABEC-1 category, ground bearings use the standard rating method used for conventional rolling-element bearings. But unground bearing capacities are generally drawn from experience, thus life values are not stated.

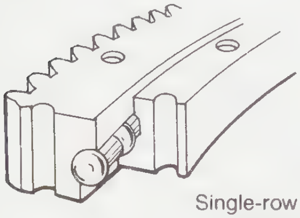
Large-diameter bearings

Large-diameter bearings have no precise definition. But a bore diameter of 12 in. or greater is used to define the size range that distinguishes large bearings from small ones. Some large bearings, such as steel-mill roll-neck bearings, are manufactured, selected, and mounted in the same way as small bearings. Inner races are interference fits, and outer races are supported in rigid housings as in small bearings.

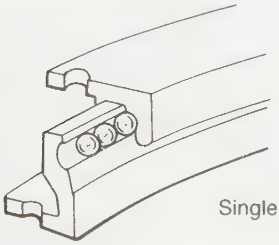
Most often, large-diameter bearings are multiload or combination load bearings. Usually, a single large-diameter bearing provides the entire support for a rotating assembly (in contrast to the conventional small bearing where two or more separate bearing assemblies support each rotating element). Also, a large-diameter bearing usually incorporates an integral means

LARGE-DIAMETER BEARINGS

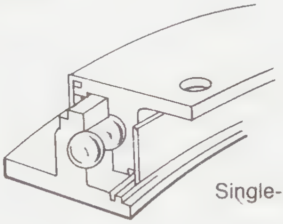
Thrust: Capacity to 1.3 million lb. Max diameter 180 in. Max speed 300 fpm. Above average tolerance to poor mounting. Low friction torque. No stock items, few standard sizes. Typical applications: Sewage and water-treatment clarifiers, large turntables.


Single-row ball with lift-off protection

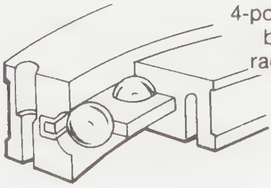
Fifth wheel: Thrust capacity is 26,000 lb. Max diameter 39 in. Max speed 100 fpm. Good tolerance to poor mounting. High friction torque. Available as stock items. Typical applications: fifth wheels, chute swivels, manual turntables.


Single-row ball

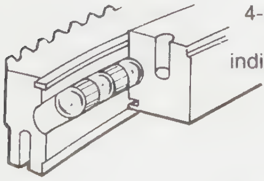
Railroad truck pivot: Capacities to 13,000-lb thrust, 68,000-lb radial. Max diameter 45 in. Max speed 100 fpm. Above average tolerance to poor mounting. High friction torque. No stock items; few standard sizes. Typical applications: Trucks for all rail vehicles.

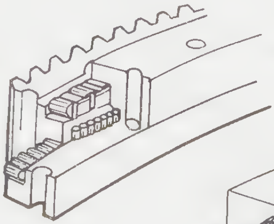

Single-row ball

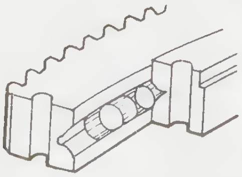
High speed: Max speed 3,000 fpm, with oil lubrication required above 1,000 fpm. Relative low load capacity. Max diameter 130 in. Low tolerance to poor mounting. Piloted mounting preferred. Low friction torque. Few stock items, some standard sizes. Typical applications: Log debarkers, coil winders, payoff reels, capstans, amusement rides.

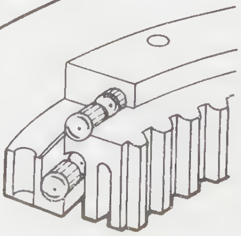

4-point contact ball with radial cage

Combined radial, thrust, and moment — heavy duty: Capacities of millions-lb thrust, over 1 million-lb radial, up to 25 million lb-ft moment. Max diameter from 130 to 180 in. Max speed 300 fpm. Tolerance to poor mounting ranges from below to above average. Friction torque is low to average. Piloted mounting seldom used. Mostly available either as stock items or specially built standard sizes except 3-row roller, which is not available from stock and has few standard sizes. Typical applications: industrial turntables, stacker conveyors, stacker cranes, welding positioners and manipulators, lift-truck rotators, metal-casting machines.

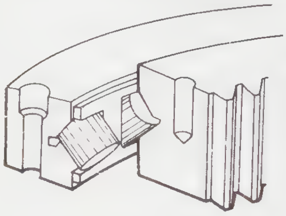

4-point contact ball with individual spacers

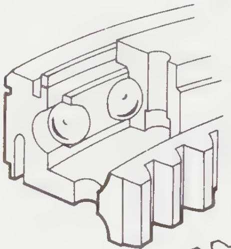

3-row roller

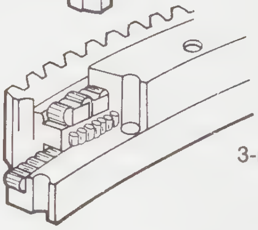

Cross roller without spacers


2-row ball with spacers

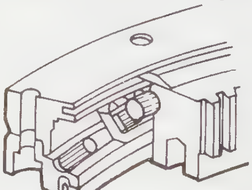
Combined radial, thrust, and moment — precision: Capacities and diameters identical to those of the heavy-duty type. Max speed 1,000 fpm. Poor tolerance to misalignment. Piloted mounting preferred. Average friction torque. Low tolerance to poor mounting. Not made as stock items; few standard production sizes. Typical applications: Precision index tables, machine tools, gun mounts, radar antenna mounts, telescope mounts.

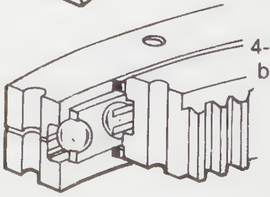

Cross roller with cage


4-point contact ball with cage


3-row roller

Inserted raceways: Capacity of four-point contact is 50% of same size solid-race bearing. Capacity of two-row roller identical to same size four-point contact ball solid race. Max diameter 130 in. Max speed 1,000 fpm.


2-roll roller with cage


4-point contact ball with edge

Above average tolerance to poor mounting. Piloted mounting preferred. Average friction torque. No stock items, few standard sizes. Typical applications: Mounts for guns, search lights, antennas.

STAINLESS STEEL MAKES THE DIFFERENCE!

The IKO line of stainless steel slides and ways gets high marks for lightweight, compact design and exceptional corrosion resistance, features that make it ideal for cleanroom applications.

① Linear Way L (Miniature type)···LWL/LWLF **Circle 290**

These extremely small linear motion rolling guides have a rail width as small as 7mm for the LWL series and 14mm for the LWLF series. They provide consistently high accuracy and rigidity for applications involving loads from all directions, including moment loads as well as combined loads.

② Linear Way H···LWHS-SL **Circle 291**

Linear Way H linear motion rolling guides feature a one-piece casing for better rigidity. They withstand moment loads and combined loads while providing reliable accuracy and rigidity.

③ Crossed Roller Way···CRW-SL **Circle 292**

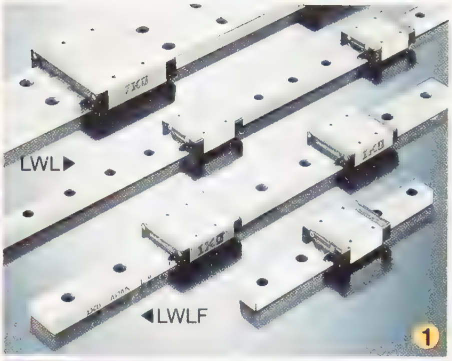
These compact linear motion rolling guides consist of high-precision cylindrical rollers running between a pair of precision ground V-ways. The Crossed Roller Ways can withstand load from any direction, ensuring high accuracy and smooth linear motion.

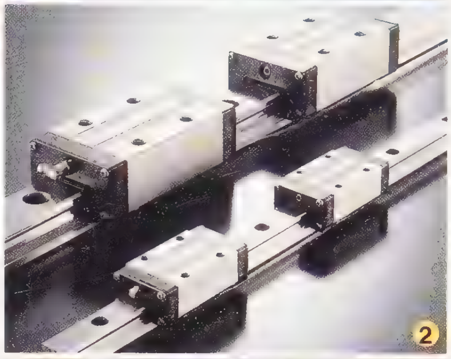
④ Precision Linear Slide···BSP/BSR **Circle 293**

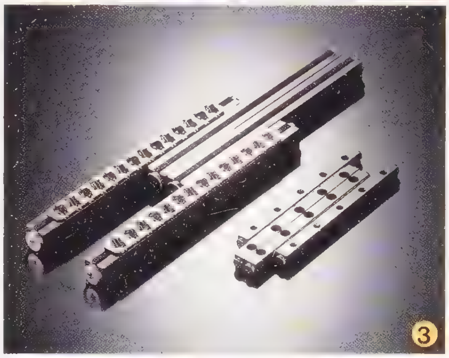
The BSP-BSR line of Precision Linear Slides are extremely compact and lightweight linear motion rolling guides made of stainless steel formed precisely into a U-shape which unifies the raceways and mounting surface. The BSP-BSR slides have a proven record of popularity as guides for read-write heads in memory storage equipment such as hard disk drives.

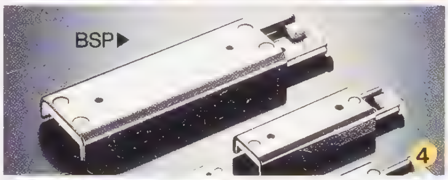
⑤ Precision Linear Slide Unit···BWU **Circle 294**

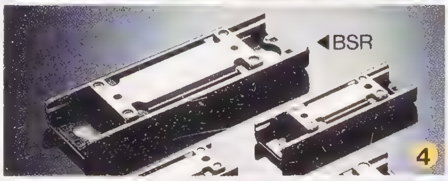
These all-stainless steel slide units feature extremely simple one-piece construction with unified table and bed. Resistant to corrosion and heat, they are perfectly suited for use in cleanroom equipment.

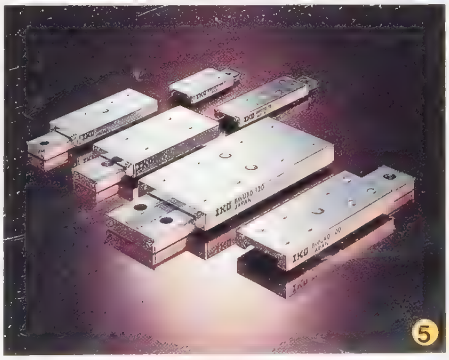












IKO

FOR FURTHER DETAILS CONTACT:

IKO INTERNATIONAL, INC.

- 500 East Thorndale Ave., Wood Dale, IL 60191 Phone: 708-766-6464 Toll free: 800-323-6694
- 2121 Paulhan St. Rancho Dominguez, CA 90220 Phone: 310-609-3988 Toll free: 800-252-3665
- 20-F Chapin Road, Pine Brook, NJ 07058 Phone: 201-882-0120 Toll free: 800-922-0337
- 2150 Boggs Road, Suite 100, Duluth, GA 30136 Phone: 404-418-1904 Toll free: 800-874-6445

of attachment, either mounting holes or weld bands. Usually integral gearing is provided on the inner or outer ring. Large-diameter bearings of this class are manufactured of steel in the 0.40 to 0.60% carbon range with a typical core hardness of 250 to 300 Bhn and with induction or flame hardening to about R_c 58 in the raceway areas.

In general, large-diameter bearings are less firmly supported by their mounting structures than small bearings. The load distribution around the bearing may be vastly different than that predicted by classic bearing formulas. To properly apply these bearings, the entire bearing-mounting-fastening system must be analyzed.

Capacity: For most applications the effective bearing capacity is some fraction of the theoretical static capacity as defined by AFBMA standards. There is no universal agreement among manufacturers as to what this fraction is. Unless continuous rotation is involved, dynamic capacity is rarely used in applying these products.

All of the AFBMA formulas assume infinitely rigid and perfectly flat mountings. The degree of reduction in theoretical capacity is largely a matter of judgment as to the extent that the actual bearing differs from the ideals of infinite rigidity and perfect accuracy. Most design is based on previous experience in similar situations.

For crane-type applications, the manufacturers' stated capacities vary from 50 to 150% of the theoretical static capacity. Service factors, again not universally agreed upon, are applied prior to selecting bearings for higher duty-cycle applications.

Premounted bearings

These units consist of a bearing element and a housing, assembled to permit convenient mounting. All components are mounted in a single unit to ensure proper protection, lubrication, and operation of the bearing.

Lubrication is provided within the units, and sealing elements retain the lubricant and exclude foreign material.

Ratings consider:

- Shaft mounting.
- Housing configuration.
- Heat dissipation.

Units from different manufacturers typically interchange and differ only in individual features.

Rigid premounted units require accurate alignment with the shaft. Therefore, overall cost may be higher than self-aligning types because of additional assembly labor.

Self-aligning units compensate for minor misalignment in mounting structures, shaft deflection, and changes which may occur after installation. Self-alignment in sleeve and some rolling types is accomplished by use of separate inner housings, into which the bearing element is assembled. A ball-and-socket action between inner and outer housings accommodates the misalignment. Some rolling bearings have spherical outer races which permit self-alignment within the bearing element.

Expansion bearings permit axial shaft movement in equipment where shafts become heated and increase in length at a greater rate than the structure on which the bearings are mounted. Under such conditions, sleeve bearings permit the shaft to move through the bearing.

Nonexpansion bearings restrict shaft movement relative to the mounting structure, and keep shaft and attached components accurately positioned. They also serve as thrust bearings within their capacity. Nonexpansion sleeve bearings usually require collars attached to the shaft at both ends of the housing. Nonexpansion roller bearings are constructed with the bearing element or inner housing mounted in the outer housing to restrict lateral movement. The bearing element is secured to the shaft by conventional methods.

Lubricants

Commercial lubricants are grouped into three generic types: oils, greases, and solid films. All three lubricate roll-

OILS

The term "oil" covers a broad class of fluid lubricants, each of which has particular physical properties and characteristics. Basically, petroleum lubricating oils are made from two types of crude oil: naphthenic and paraffinic.

Naphthenic oils contain very little wax, and their low pour point makes them good lubricants for almost any application. Paraffinic oils, on the other hand, are very waxy, and lubricants made from them are used mainly in hydraulic equipment and other machinery.

Each different oil possesses certain properties that govern its suitability for a particular application. Of all these properties, the most important is viscosity.

Viscosity is a measure of flowability; that is, the resistance to flow caused by internal friction between the lubricant molecules. This characteristic determines load-carrying capacity, thickness of the lubricating film, and operating temperature.

Viscosity can be expressed as the number of seconds required for a measured volume of oil to flow through a specified orifice at a standard condition. In the U.S., 100°F and 210°F have traditionally been the temperatures at which viscosity is specified and measured.

Viscosity index is a measure of how viscosity varies with temperature. This property can be an important consideration in applications where operating temperatures vary widely, particularly if low temperatures are encountered.

Naphthenic oils have low viscosity indexes, and paraffinic oils generally have high indexes, depending on the refining process. The viscosity index of both oils can be improved with additives, although additives are seldom used with naphthenic oils.

Pour point is the lowest temperature at which an oil will flow. Obviously, it is an important criterion in low-temperature applications. In paraffinic oils, failure to flow is caused by the formation of wax crystals, while in naphthenic oils, failure to flow is caused by excessively high viscosity. At comparable viscosities, naphthenic oils have lower pour points than paraffinic oils. Also, the pour point of paraffinic oils can be lowered by adding pour point depressants.

Flash point is the temperature at which the oil gives off ignitable vapors. **Fire point** is the temperature at which an oil will burn if ignited. The flash point is not necessarily a safe upper limit for an oil because some decomposition takes place below the flash point.

Oxidation resistance is related to the service life of an oil. Oxidation rate depends on temperature, the amount of oxygen present, the presence of catalytic metals. Usually, temperature is the most important factor because oxidation rate doubles for each 18°F temperature rise. The effects of oxidation include the formation of gums and acids, and increased viscosity.

Bearing grease characteristics

Grease thickener	Base oil	Temperature range (°F)	Oxidation resistance	Anticorrosive properties	Water resistance	Remarks
Calcium	Mineral	10 to +150	Good	Good (with additives)	Very stable, water-repellent	Good sealing action against water; no absorption of leakage water
Sodium		−15 to +120	Good	Good	Unstable	Emulsifies with little water but may liquefy during emulsification
Lithium		−20 to +250	Very good	Good (with additives)	Stable up to 195°F	Emulsifies with little water, but softens with more water. Universal rolling bearing grease
Lithium	Diester	−70 to +250	Very good	Good (with additives)	Stable up to 195°F	Low-temperature grease; also good for high speeds; low friction
	Silicone	−40 to +350			Stable	Suitable for high temperature and light loads
Calcium complex	Mineral or synthetic	−15 to +270	Very good	Good (with additives)	Very stable, water-repellent	High-pressure grease
Sodium complex		−20 to +290	Very good	Good (with additives)	Stable up to 175°F	Suitable for high temperatures and loads
Barium complex		−20 to +290	Very good	Good (with additives)	Stable up to 175°F	Suitable for higher temperatures, loads, and speeds (depending on base oil)
Polyurea*	Synthetic or mineral	−20 to +350	Very good	Good (with additives)	Stable	High temperature grease, also for high loads and speeds
Arylurea	Silicone	−100 to +400	Very good	Good (with additives)	Stable	Suitable for high temperatures, low speeds and light loads
Gel*	Diester	−90 to +250	Very good	Good (with additives)	Stable	Suitable for high temperatures at low speeds
	Synthetic hydrocarbon	−60 to +350	Very good	Good (with additives)	Stable	Suitable for high temperatures at low speeds
Bentonite	Mineral	−5 to +350	Very good	Good (with additives)	Very stable	Suitable for high temeratures at low speeds

*Also available as EP grease

GREASES

Greases are mixtures of lubricating oil and organic or inorganic vehicles that keep the oil in suspension. The most common greases are made from metallic soaps. Most nonsoap greases have inorganic thickeners, but urea thickeners are used in some applications.

Greases are usually ranked by their relative hardness on a scale set up by the National Lubricating Grease Institute. The softest greases are rated at 000, with higher numbers indicating harder greases. Most greases fall in the range of 1 to 6.

Another common rating method for greases is their dropping point. Dropping point is defined as the temperature at which oil separates from the grease. As a rule of thumb, a temperature 50°F less than the dropping point is the maximum operating temperature for the grease.

Calcium, or lime soap greases are used to lubricate bearings at temperatures up to about 200°F. Above that temperature, the grease tends to separate and does not reform when cooled. Dropping point is about 250°F.

Sodium soap, or soda greases can be used at temperatures as high as 250°F. At the upper limits of the temperature range, their sealing qualities are reduced, but lubricating abilities are unaffected. Soda greases have a dropping point about 390°F.

Lithium soap greases lubricate well over a broad range of conditions. They are reasonably resistant to water, have favorable high and low-temperature capacity, and good oxidation stability. Their dropping point is 380°F, and their maximum operating temperature is about 300°F.

Barium soap greases generally have high resistance to water washout and a dropping point above 500°F.

Aluminum soap greases have good water resistance and are widely used for low-speed ball and roller bearings and for chassis lubrication. However, they have a dropping point of about 170°F.

Lead soap greases have good extreme-pressure characteristics and are used for heavy-duty gears.

Mixed-base greases combine two soap bases, to improve the shear stability of the grease. When one component is a lead soap, the grease is usually found in extreme-pressure applications.

Complex soap greases are quite stable at high temperatures and have dropping points above 450°F. The most common are calcium complex and aluminum complex greases.

Nonsoap thickeners include silica gel, carbon black, treated clay, copper phthalocycaine, and aryl substituted ureas. Nonsoap greases do not have dropping points, so their temperature limits depend on the oil components. However, the generally higher temperature limits are accompanied by the need for more frequent relubrication.

Analyzing bearing lubricants

Lubricant	Symptom	Cause
Oil or grease	Reddish deposit at ball contact	Indicates fretting corrosion. Look for oscillatory or vibratory motion during operation.
	Metallic particles accompanied by indication of wear on bearing components.	Lubrication failure or external contaminant.
Oil	Dry surfaces with little evidence of residue, or slight brownish haze on ball and raceway surfaces.	Too little lubricant, either initially or because of oil migration.
Grease	Grease darkened but still oily	High loads or contaminants.
	Grease darkened and dry.	Extreme high loads or contaminants.
	Grease surface dry and hard, soft interior.	High external heat.

SYNTHETIC LUBRICANTS

Synthetic lubricants can extend the life of equipment that operates at extreme temperatures; some eliminate fires or oxidation with highly reactive materials; and they reduce maintenance and downtime by greatly extending lubrication intervals.

Synthetics are normally classified as specialty lubricants for unusual applications. The single exception is the aerospace industry, which has adopted synthetics wholeheartedly — for the simple reason that they are the only lubricants that work in many high-speed extreme-temperature applications. Industrial applications have lagged for several reasons: petroleum lubricants do an adequate job in most situations, the cost of synthetics is four to ten times that of their petroleum counterparts, and synthetics are in limited supply.

The label synthetic lubricants covers a broad category of fluids and pastes having specific properties. Most are hydrocarbon based, produced by a reaction between one of several fatty acids and alcohol and phenol. They are available in a variety of forms, from light oils to thick greases.

The first synthetic lubricants were the polyglycols, also known as glycols and polyethers. They are known for their excellent viscosity index, high-temperature stability, and low sludge buildup at high temperatures. On the negative side, polyglycols are unsuitable for applications below −40°F. But, most importantly, common additives are insoluble in glycols.

Other early synthetics were the phosphate esters. Their advantages include high lubricity and nonflammability. However, they have only fair viscosity index and thermal stability, and they are volatile.

Chlorofluorolubricants provide good resistance to extremely corrosive materials because they are inert to oxygen, nitric acid, and hydrogen peroxide. Available as oils and greases, they are stable to about 500°F, but begin to depolymerize slowly at about 550°F.

Extremely high-temperature problems are handled by the polyphenyl esters, which can withstand up to 1,000°F. These lubricants fail at low temperatures, but most are fluid at room temperature. Polyphenyl ethers also are one of the best lubricants for carrying extreme loads.

The most widely recognized synthetic lubricants are the silicones. Their structure gives them excellent high-temperature properties and resistance to corrosive fluids. Outstanding features include least change in viscosity of all synthetics, wide temperature range, good thermal stability, and good oxidation stability. On the negative side, silicones have only fair load-carrying ability, often permitting surface to surface contact in boundary-lubricated applications.

Finally, the synthetics that have the best chance to make inroads on petroleum-based oils are the dibasic acid esters, or diesters. Their assets include stable viscosity over a wide temperature range, high film strength, good metal wetting, and low vapor pressures at elevated temperatures. Also, these lubricants accept additives readily.

SOLID LUBRICANTS

Physical requirements for solid lubricants are resistance to pe
etration by surface peaks under extreme loads, and ability
shear more easily than the base material. Although there a
many possible materials, the most common and practical a
molybdenum disulfide, graphite, PTFE, and nylon.

Molybdenum disulfide is usually applied in a grease,
dispersion, or a paste. It has important advantages when high
finished surfaces are to be lubricated and when low concentr
tions of lubricant are required. In oxidizing atmospheres, moly
denum disulfide is limited to 750°F, but much higher operati
temperatures are feasible if oxygen is not present.

Graphite has better properties above 750°F than molybd
num disulfide, and is particularly applicable when electric
conductivity is important. Complete oxidation of graphite pr
duces carbon dioxide gas, and no abrasive residues are forme
However, graphite generally is not suitable in vacuum, and t
AFBMA normally does not recommend it for rolling-eleme
bearings.

Powdered solid lubricants and bonded dry films

Lubricant	APPLICATION Vacuum	Radiation	Sleeve bearings	Anti-friction bearings
Molybdenum disulfide	E	E	E	L
Graphite	L	E	G	L
Teflon	G	G	E	As retainers
Bonded coatings				
Organic binders	L	L	E	L
Inorganic binders	E	E	G	L

E = excellent, G = good, L = limited use.

Solids for dry lubrication

Lubricant	Load† (psi)	Temperature (°F)
Molybdenum disulfide, commercially available particle-size grades	To yield point of metal	−300 to +750*
Graphite powder, lubricating grade	To 100,000	−300 to +1,200
Tungsten disulfide powder commercially available	To yield point of metal	Low not investigated Maximum 850°
Teflon powder and sintered shapes	To 3,000	−300 to +500
Teflon and other plastics containing fillers	To 4,000	Maximum 500
Resin binder coatings, graphite-MoS_2 type	To yield point of metal	−100 to 600
Inorganic binder coatings, graphite-MoS_2 type	2,000 to yield point of metal	−300 to 1,500

*In inert and reducing atmospheres these solids are used at temperatures above 2,000° F.

†Speed affects performance to a marked degree, but solid lubricants should only be considered at low speeds.

Nylons are used primarily in the form of molded parts. The
bearing properties can be improved by filling with other sol
lubricants such as molybdenum disulfide or graphite. The
coefficients of friction are not as low as that of PTFE, but th
are generally harder, and can be used where loads are higher a
speeds lower. Nylon-based lubricants also do not have as mu
chemical and thermal resistance as PTFE, but are much le
expensive.

PTFE is an excellent lubricant for loads less than 5,000 p
but is not as good as molybdenum disulfide or graphite at high
loads. Powders of PTFE can be dispersed in water, oils, greas
solvents, elastomers, and other plastics, and can be burnish
onto a metallic substrate. Greases fortified with PTFE seem
be superior to molybdenum disulfide or graphite for some s
metals, including zinc and die-cast metals.

ing and sliding bearings and gears, and solid lubricants are used in all but the most lightly loaded gears. Each general type has assets that best equip it for certain applications.

Lubricating systems

Simple fittings and single-point devices up to automatic centralized systems can be considered lubricating systems. They are classified as internal if the reservoir is inside the housing and external if it is outside. Internal devices are usually part of the original equipment design, while external devices are often proprietary.

Manual lubrication

Manual lubrication requires the use of a portable pump, which is not part of the machine, and an oil cup or grease fitting. Tubing or drilled passages carry the lubricant from the fittings to the friction points. Lubricant is applied by connecting the pump outlet to the fitting and injecting a specified amount of lubricant.

Self-lubrication

In this process, the material is inherently self-lubricating or the mechanism does the work of delivering lubricant to

BONDED DRY FILMS

Bonded dry films include solid lubricants, solvents, and binders. Such dry films are applied onto wear surfaces as coatings. Solvents keep lubricants in suspension until the coating is cured, whereas binders hold lubricants on the wear surface.

Optimum wear life of a dry film is achieved with an initial coating thickness of 0.5 mil. Thicker films seem to have little adverse effect, but thinner films may drastically reduce service life of the coating.

Generally, harder substrates promote better coating life than softer ones at given operating conditions. Optimum wear life is obtained when substrate hardness is about 60 R_c and the surface has been finished to 15 to 30 μin.

Several developments have improved the corrosion-protective properties of dry films. Combinations of inorganic oxides and phosphates with solid lubricants in thicknesses of 0.5 to 0.7 mil have withstood 100 h of 5% salt spray fog. These coatings maintain the good lubricating qualities of other dry films.

OIL AND GREASE ADDITIVES

Materials can be added to oils and greases to enhance their lubricating abilities. These additives are usually chemical compounds that fortify one or several of the lubricant's properties.

Oxidation inhibitors impede the formation of gums and acids by slowing down chemical oxidation. They are usually phosphorous, sulfur, nitrogen, or organic compounds.

Defoamers are compounds — often silicones — that minimize the generation of foam. They are usually used in lubricants for high-speed bearings.

Detergents keep insoluble materials in suspension in the oil. They are most common as additives in oils for internal combustion engines.

Rust inhibitors are usually surface-active agents that plate themselves out on ferrous surfaces to protect against rust formation.

Pour-point depressants prevent wax crystals from jelling at low temperatures.

EP additives react with metals to form antiweld compounds, and help reduce wear. They are usually compounds of phosphorus, lead, sulfur, or chlorine.

Synthetic properties

Base-oil type	Lubricity, antiwear, EP†	Fluid range	Viscosity index	Volatility	Additive response	Oxidation stability	Thermal stability	Hydrolytic stability	Fire resistance	Compatibility with petroleum lubricants	Compatibility with paints, plastics, & elastomers	Cost
Conventional petroleum	G	F	F	P	FG	F	F	E	P	E	FG	Very low
Super-refined petroleum and synthetic hydrocarbons	G	G	G	G	VG	G	G	E	P	E	G	Med. high
Esters	VG	VG	VG	G	E	G	FG	G	F	VG	FP	Medium
Silicones	FG	E	E	G	FG	G	G	VG	F	FP	G	High
Polyethers (polyalkylene glycols)	G	G	E	F	F	F	VG	G	F	F	F	Medium
Phosphate esters	E	F	F	F	G	FG§	F	FP§	VG	G	P	Medium
Silicate esters	F	E	E	G	F	F	VG	P	F	F	F	High
Highly fluorinated compounds	G	F	P	FG	P	E	VG	VG	E	P	G	Very high
Polyaromatics (polyphenyls and polyphenyl ethers)	F	P	P	G	F	G	E	E	F	G	F	Very high

*E = excellent, VG = very good, G = good, FG = fairly good, F = fair, FP = fairly poor, P = poor.

†For metals, particularly steel-on-steel.

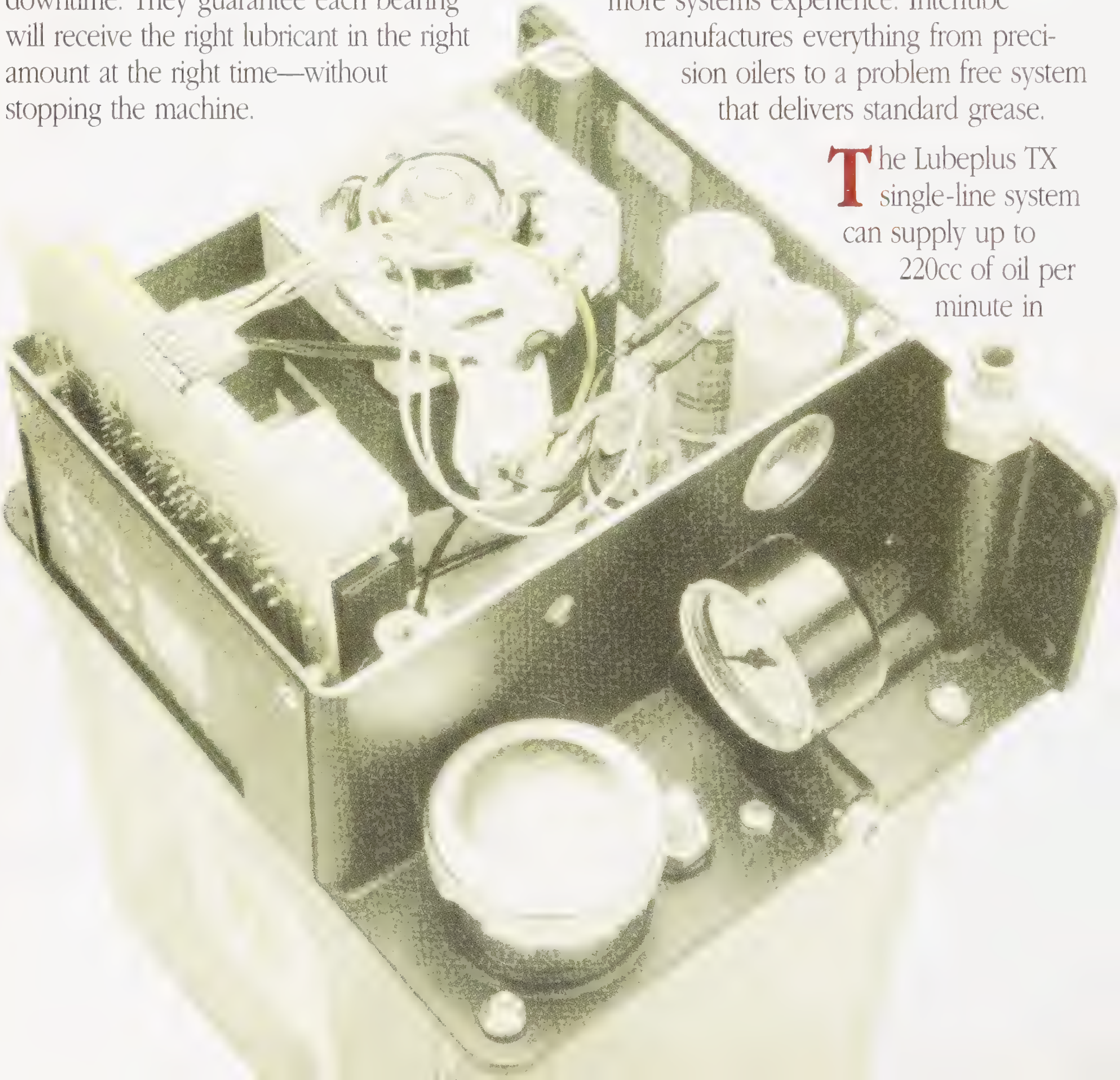
§Degradation products are strongly corrosive.

Lube 'em Automatically:

Automatic machine lubrication systems lengthen operating life, improve productivity, reduce parts failures and downtime. They guarantee each bearing will receive the right lubricant in the right amount at the right time—without stopping the machine.

But there are many types of systems available. Ask Robertshaw Interlube about your options. Nobody in North America has more systems experience. Interlube manufactures everything from precision oilers to a problem free system that delivers standard grease.

The Lubeplus TX single-line system can supply up to 220cc of oil per minute in



precision amounts. That's enough to handle all the bearings on some assembly lines. Pressure control is variable for use with injectors or flowmeters. A microprocessor operates on timed or impulse count control, including an automatic pre-lube cycle. It also senses any drop in line pressure and can stop machine operation. In presses, where flexible lube lines servicing the crank bearing can eventually break, this protection is a must. Another TX model, without microprocessor, can be interfaced with CNC machine controls.

An economical, single-line oil system, the Lubeplus E, is designed with an output of 2.5cc per cycle, an efficient size for smaller or ancillary machines with operators. Pre-lube is manual. Pump operation is electric, cycles are timed and delivery is through flowmeters to about 16-30 points.

Robertshaw
INTERLUBE
XGS
INDUSTRIAL LUBRICATION SYSTEM
MINIMUM LEVEL
Robertshaw Controls Co. • Tennessee Division
Knoxville, TN 37901

There is no more reliable system for lubrication with standard grease than the multiple-line Interlube XGS. The grease pump is air operated, servicing 12 to 72 injectors on a time cycle basis. The XGS is ideal for automated machines in food, paper and other "drip" sensitive industries.

An economical multiple-line version, the Interlube MX, electrically pumps fluid grease or oil to as many as 36 points.

Installation of all systems is easy and pricing is extremely cost-efficient. For information on Interlube automatic lubrication systems, phone **(800) 228-7429.**

Robertshaw
TENNESSEE
A SIEBE COMPANY

Oil to Heavy Grease.

P.O. Box 400 / Knoxville, TN 37901-0400 / (615) 546-0550 / FAX (615) 544-5193

Circle 295

critical points. Examples of the latter are oil splash systems, oil slingers, and oil baths.

Single-point devices

Single-point lubrication is similar to separate lubrication because each friction point is distinct. However, in single-point lubrication, an oil or grease reservoir delivers lubricant over some time period, and the reservoir is refilled periodically.

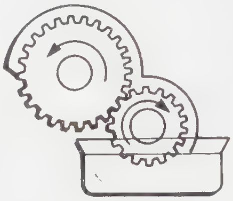
For grease lubrication, pressurized injectors or grease cups are used. Grease flow rate is controlled by spring pressure and an orifice. Oil systems use a container plus an orifice or wick to control the flow.

Centralized systems.

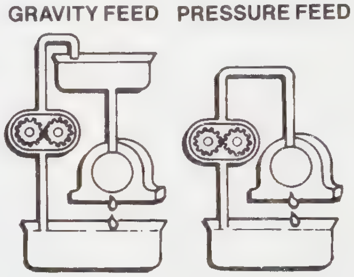
Centralized lubricating systems lubricate all the friction points from a single pump source. The pump can be manual, mechanical, or motor operated. Positive pressure controls the flow rate and also provides a means of indicating correct operation or malfunction. Also, these systems can shut down a machine if required. ■

INDEPENDENT SYSTEMS

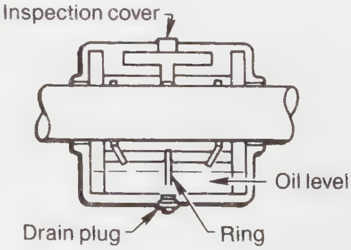
Bath lubrication is the simplest internal-reservoir methods of lubricating multiple drive elements. It is most often used for enclosed gear and chain drives and vertically mounted thrust, step, and spindle bearings.



Flood lubrication: Most machinery with internal multipoint lubrication uses flood lubrication, with either gravity or pressure feed. These systems are suitable for all types of drive components. Flood lubrication can also be used to augment an internal reservoir.



The **ring oiler** is the simplest single-point circulating-lube system. It is most effective on large, medium-speed, horizontally mounted, plain bearings. An adaptation of the ring oiler places a fixed collar on the shaft to contain the oil.



Single-point lubrication: The drop-feed, or gravity oiler is the most common external reservoir for single-point lubrication. A needle valve regulates oil flow, and a sight glass in the shank permits observation of lubricant level.

On individual units, a lever at the top of the reservoir opens and closes the needle valve to start or stop flow without disturbing valve setting.

CONTROLLING BONDED DRY FILMS

Coating properties are controlled by the selection of solid lubricants, binders, pigments and additives. For example, coating friction and release characteristics are determined primarily by solid lubricant selection. Most new low-friction coatings have at least some fluoropolymers, usually PTFE. Generally, the suspended PTFE coatings with polyimide binders have the best friction and wear properties.

Factors such as pressure, speed, and temperature can affect the friction coefficient of bonded coatings. However, with bonded PTFE coatings, friction coefficient remains constant, typically about 0.04, for loads that range from 0.2 to 400,000 psi. Below 0.2 psi, frictional characteristics are erratic. Static and dynamic friction coefficients are about the same for bonded PTFE coatings. Also, friction coefficients remain constant for a temperature range from −422 to 550°F. Although PTFE friction coefficient increases with speed up to about 150 fpm, it still is relatively lower than that of other solid lubricants. Above 150 fpm, there is little change in friction coefficient unless the interface temperature exceeds 600°F. This does not happen often because the thin bonded films dissipate frictional heat rapidly.

Stick-slip (chatter) is virtually nonexistent with PTFE coatings at low speed or pressure because the PTFE film transfers to the mating surface and because dynamic and static friction coefficients are nearly identical. For applications in which materials must not adhere to a bonded coating, the release characteristics are improved by buffing the coating before initial use. Bonded coatings applied to the sole plates of household irons must have good release characteristics to keep starches, silicones, and other ironing aids from adhering to the coating. As an alternative to buffing, the coating can be cured at least 75°F above its anticipated service temperatures.

Bonded coatings can be formulated to have wear resistance comparing favorably with filled-PTFE composites. Typically, these wear-resistant coatings are based on either polyimide, PPS, or phenolic resin binders. Moreover, such coatings can be subjected to operating conditions characterized by *PV* values greater than 50,000 psi-fpm. A PTFE coating with a PPS resin binder provides good abrasion resistance if service temperatures are kept below 300°F.

PTFE coatings also can be formulated to act as barriers to protect the substrate from fluids. Depending on the combination of resin binder and additives, these coatings are unaffected by tap water, salt water, solvents, bleaches, soaps, and refrigerants. Also, lubricants such as greases and oils do not harm these coatings. For example, most corrosive aircraft hydraulic fluids such as the phosphate esters do not soften or remove bonded coatings. This characteristic allows bonded coatings to be used as backup lubricants that can prevent seizure if the system should lose the primary lubricants.

LIQUID LEVEL GAGES & SWITCHES

THOUSANDS OF MODELS TO FIT ANY APPLICATION

- Hydraulic Tanks
- Gear Boxes
- Bearings
- Etc.

Steel, Stainless Steel, Brass, Tough Plastic or Flexible Plastic.

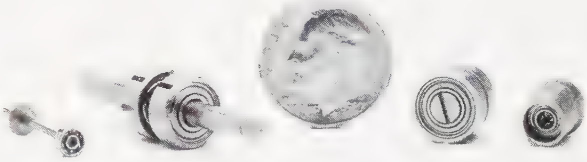
Write For Catalog.

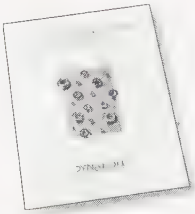
Oil-Rite®
CORPORATION

SECTION 76
P.O. BOX 1207
MANITOWOC, WI 54221-1207
PHONE (414) 682-6173
FAX (414) 682-7699

Circle 296

. . . TO DYNAROLL FOR EXPERT ADVICE ON MINIATURE PRECISION SUBASSEMBLIES.



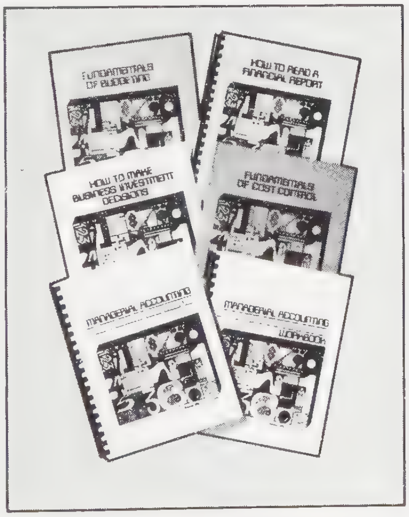


Whether your need is for miniature bearings or precision custom subassemblies, get the right product for your application by calling DYNAROLL.

OVER ONE MILLION BEARINGS IN STOCK!

DYNAROLL
CORPORATION
551A Fifth St., San Fernando, CA 91340 · 818-837-3456 Fax: 818-837-3466

Circle 297



WHAT EVERY MANAGER NEEDS TO KNOW ABOUT ACCOUNTING

in this Easy-To-Use Self-Study Course Series

A 50-hour course of instruction at less than $2.00 per hour. Study them one-at-a-time . . . or buy all five courses at a special savings. Either way, 15-day review option applies.

Item X38 ***Managerial Accounting for Non-Financial Managers*** *course and work book* $32.50
Item X30 ***Fundamentals of Cost Control*** $20.00
Item X29 ***How to Read a Financial Report*** *(ratio analysis)* $24.00
Item X36 ***How to Make Business Investment Decisions*** *(the time value of money)* $20.00
Item X15 ***Fundamentals of Budgeting*** $20.00
Item S08 ***The Complete Five-course Financial Planning Series at a special price of $99.50 (save $17).***

Begin your personal financial development program today.

Complete the coupon below and mail to:
Penton Education Division • 1100 Superior Avenue • Cleveland, Ohio 44114 • 216/696-7000

Please send the items checked below. I understand that I may review them for 15 days and, if not satisfied, return them for full refund or credit.

Quantity	Item No.	Quantity	Item No.
______	X15	______	X36
______	X29	______	X38
______	X30	______	S08

☐ My payment is enclosed for postage-free shipment in the U.S. and Canada.
☐ Bill my company. My purchase order is enclosed.
Charge my ☐ Visa ☐ MasterCard ☐ American Express.
Acct. No. ____________ Exp. date ______

Name ____________
Title ____________
Company ____________
Address (no P.O. Box) ____________
City ____________ State ______ Zip ______
Signature ____________
☐ Please send your brochure of other management, professional and technical courses.
Penton Education Division • 1100 Superior Avenue
Cleveland, Ohio 44114

MECHANICAL SYSTEMS

Write this number on the Reader Service Card to receive information from all advertisers making the listed products.

FIXED-SPEED DRIVES

1130 Belt
1131 Chain
1132 Gear
1133 Reversing

ADJUSTABLE-SPEED DRIVES

1134 Belt
1135 Chain
1136 Friction
1137 Gear
1138 Variable-stroke
1139 Other

DRIVELINE COMPONENTS

1140 Actuators
1141 Adapters, load
1142 Axles
1143 Belts
1144 Belts, conveyor
1145 Brakes
1146 Cams
1147 Chains, conveyor
1148 Chains, transmission
1149 Clutches
1150 Controls, cable
1151 Conveyors, roller
1152 Counters & timers
1153 Cranks
1154 Flexible couplings
1155 Flexible shafts
1156 Fluid couplings
1157 Hoists
1158 Idlers
1159 Jacks
1160 Leadscrews
1161 Linkages
1162 Manipulators
1163 Mechanisms, gyratory-motion
1164 Motion converters
1165 Power absorbers
1166 Power takeoffs
1167 Propellants
1168 Propellers
1169 Pulleys & sheaves
1170 Racks, gear & pinion
1171 Refrigeration
1172 Screws, conveyor
1173 Separators
1174 Spindles
1175 Splines
1176 Spring motors
1177 Sprockets
1178 Subassemblies, machine & instrument
1179 Subsystems, machine base
1180 Tables, indexing & positioning
1181 Tensioners
1182 Torque converters
1183 Torque limiters
1184 Transfer cases
1185 Universal joints
1186 Vibrators

BEARINGS AND LUBRICANTS

1187 Bearings, ball
1188 Bearings, pillow block
1189 Bearings, plain
1190 Bearings, roller
1191 Cam followers
1192 Lubricants
1193 Slides & ways

SEALS, PACKINGS, AND GASKETS

1194 Bellows
1195 Diaphragms
1196 Diaphragms, rolled
1197 Gaskets
1198 O-rings
1199 Packings
1200 Piston rings
1201 Seals, fluid
1202 Seals, material
1203 Seals, mechanical
1204 Seals, other
1205 Wiper rings

FASTENING, JOINING & ASSEMBLY

Advertisers

Anchor Bolt & Screw Co. 361
Aremco Products, Incorporated 327
Associated Spring,
Barnes Group Inc. 377
Camcar Division of Textron, Inc. ... 363-366
Camloc Products/Fairchild
Fastener Group 343-346,351-354
Carr Lane Mfg. Co. 321-322
Driv-Lok Incorporated 381
Eaton Corporation,
Engineered Fasteners Division ...349,391
Eberhard Manufacturing 393
Eskay 368
Fairchild Aerospace Fastener
Division 340-341
Fishertech, Division of
Fisher Gauge Ltd. 311-314
Gesipa Fasteners USA, Inc. 386
Groov-Pin, Inc. 384
Industrial Retaining Ring Co. 382

A
Adhesives 315
Anchor nuts 339
Arc-welded studs 360
B
Blind rivets 369
Bolted joint uncertainties 382
Bolts, screws, studs 355
Brazing processes 323
C
Cable and tube retainers 392
Caged nuts 342
Captive nuts 338
Captive screws 355
Castle and slotted nuts 338
Choosing special fasteners 390
Clinch nuts 342
Clinching 330
D
Dart-type spring clips 392
Designing for reliability 333
F
Formed-metal fasteners 393
Free-spinning nuts 338
H
Hose clamps 403
I
Injected metal 330
Inserts 348
J
Jam nuts 338
Joining composites 328
Joining plastic 325
L
Locking devices 359
M
Metals and ceramics 329
N
Nuts 338
P
Pierce nuts 343
Plastic fasteners 393
Prevailing-torque nuts 338
Q
Quick-operating fasteners 395
Quick-release pins 378

Joining

Joint design

Threaded fasteners

Nonthreaded fasteners

Special-purpose fasteners

Lexington Company, The 355
Long Lok Fasteners Corp. 399
MMFG 358
Marlboro Manufacturing, Inc. 399
Master Bond Inc. 327
Panduit Corporation 389
Paneloc Corporation, The 403
Rolex Company, National Disc
  Spring Division 389
Rotor Clip Company 388
SPS Technologies, Aerospace
  Products Division 359
Simmons Fastener Company 398,400,402
Smalley Steel Ring Company 370-373
Southco, Inc. 396-397
Stabilus 389
Stafast Products, Inc. 355
Stimpson Company, Inc. 375,379,383,387
Stocker Hinge Manufacturing Company 392
Tridair Fasteners, Fairchild
  Fastener Group 340-341
USA Tolerance Rings 386
Yardley Products Corporation 357

R
Resistance-welded fasteners 359
Retaining rings 380
S
Self-clinching nuts 342
Self-piercing nuts 343
Self-sealing fasteners 404
Semipermanent pins 376
Setscrews 356
Shaped spring clips 392
Single-thread nuts 348
Soldering processes 320
Spiral-wound rings 385
Spring clips 390
Stable bolted joints 331
Stamped rings 380
Stud receivers 390
Studs 359
T
Tapping screws 355
Tubular rivets 369
W
Washers 386
Welded fasteners 359
Welded joints 333
Welding 318
Wire-formed rings 380

Technical information for this section was supplied in part by The Industrial Fasteners Institute, Cleveland, Ohio.

Answering the productivity challenge

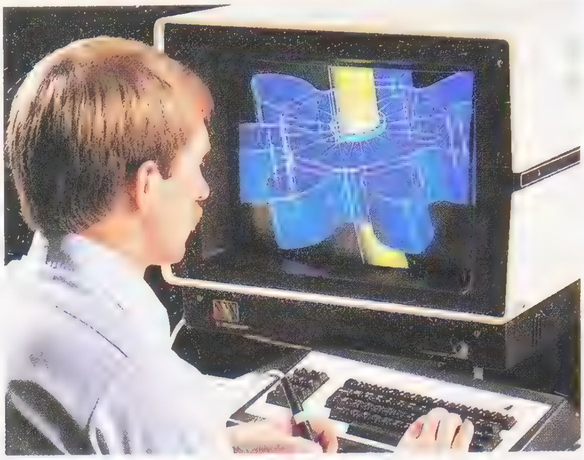
INJECTED METAL
ASSEMBLY SYSTEMS

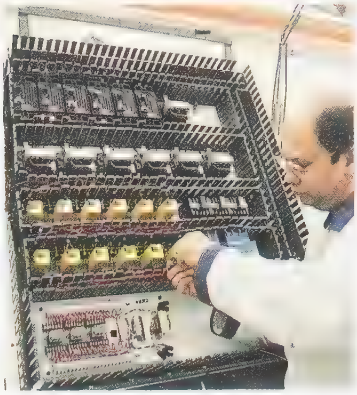
FISHERTECH
DIVISION OF FISHER GAUGE LIMITED

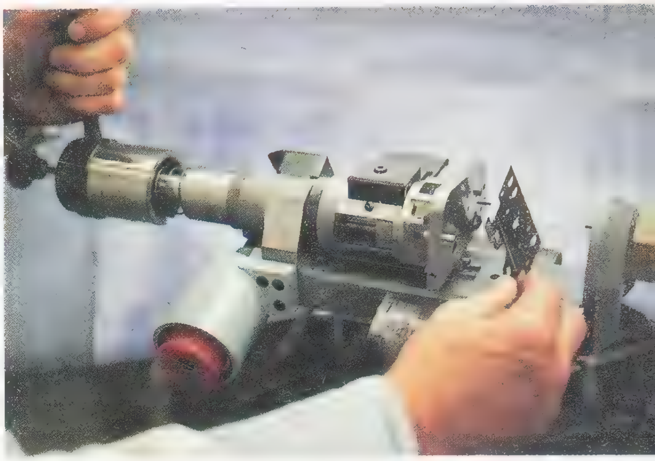
P.O. Box 179, Peterborough, Ontario, Canada K9J 6Y9
Telephone: (705) 748-9522 TELEX: 06-962838 FAX: (705) 748-6312

Circle 298

A problem-solving technology







One of the greatest strengths of Fishertech over the last 50 years has been the ability to solve assembly problems with Injected Metal Assembly. Fishertech engineers welcome challenges and work closely with customers to develop cost-effective solutions.

IMA systems are used in over 45 countries and have earned a solid reputation for productivity and reliability, combined with innovative engineering. Today, IMA machines are capable of being integrated into automated or Flexible Manufacturing Systems, and offer exciting productivity advantages to manufacturers.

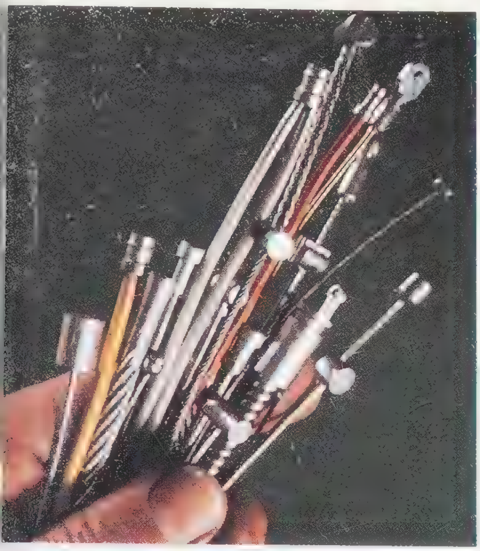
The benefits are proven.
Now, what can IMA do for you?
The very first Injected Metal Assembly machine was developed to solve a specific manufacturing problem. After forty years it is still in use. Later generations of the machine are working to provide an extensive range of solutions. When you add IMA to your production capabilities, you're putting our experience to work for you. The following important production benefits are available to you.

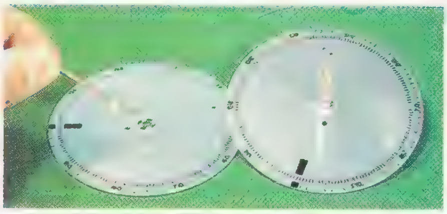
Simpler parts manufacture. Parts to be assembled by IMA are located by their functional surfaces and held in their correct relationship by custom-made tooling. The accuracy of the final assembly is not dependent on the position or dimensional accuracy of fixturing holes, thus simplifying manufacture.

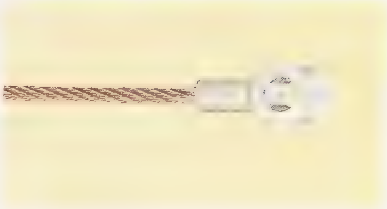
Fewer pre-manufactured parts. IMA is a development of the die casting process, and can form parts in place as it assembles them. The necessary mold is built into the tool, so the operation is completed in one machine cycle. Parts such as pinions, cams, hubs, sleeves rivets, etc. no longer need to be manufactured or purchased, but can be precisely cast. For example, as a shaft is assembled to a gear, a pinion can be formed in place; or as a rotor for an electric motor is assembled to a shaft, a hub can be cast to eliminate the need for spacers and washers.

By eliminating many parts needed by other assembly techniques, IMA reduces both inventory costs and assembly times.

Quick-changes to a new assembly. The custom-made assembly tool is carried in an operating head. The tool itself can be adapted by means of inserts, to handle variations of







an assembly. Different types of assembly can be accommodated by changing the tooling in the operating head, or if the assembly is radically different the entire operating head can be quickly interchanged.

Multiple operations combined. With appropriate design, IMA can assemble in one operation parts which previously took several operations. For example, several rivets can be injected in one cycle, or several parts can be joined to a shaft at one time.

Secondary operations eliminated. As they leave the machine, assemblies are ready for the next stage of production. The assembly is free of flash and sprues and requires no cleaning, finishing or secondary operations.

Permanent assembly. As the injected metal cools, it shrinks, forming a powerful mechanical lock. The assembly can only be taken apart by destroying the components. Tests of IMA assemblies regularly show that the injected metal hub is stronger than the components which it joins.

Minimum Quality Control. The tool on the IMA machine locates parts precisely. In many cases, the tool functions as a parts inspection fixture and will reject out-of-tolerance components. The process is predictable and consistent, with virtually no variation from part to part. Inspection can therefore be reduced or even eliminated.

New design freedom. Applying die casting technology to the assembly process provides a new range of solutions for product design. Fishertech design engineers are ready to help achieve a solution. With IMA it is possible to avoid many of the restrictions imposed by other assembly methods. Time and again IMA users discover new ways to get results!

As much automation as you can use. Components can be loaded into the assembly tool either manually or automatically. The injection and unloading cycle is automatic. Component-loading devices are recommended for long runs.

Of course complete automation is possible. Fishertech has designed and built fully automatic high-production IMA machines, loaded and unloaded by robots, capable of operating for extended periods without attention.

All systems can work directly in the assembly line or as stand-alone units producing batches of parts.

IMA brings it all together: low cost, precision, and new design freedom.

Injected Metal Assembly (IMA) enables small parts to be permanently assembled in precise configurations more economically than many traditional methods. Since the process was first developed for general manufacturing by Fishertech, IMA has been applied to many different types of assembly, joining not only metals but materials as diverse as ceramics, glass, paper, elastomers and a wide range of plastics. The only limitation on its application to small parts assembly appears to be the imagination of the user.

Every manufacturer today must face the productivity challenge; how to create better quality products at lower cost. IMA, a technique proven reliable over many years of use, offers opportunities which no manufacturer of small assemblies can afford to ignore.

The parts to be joined by IMA are first placed in a tool which holds them in their correct relationship. A molten alloy, usually zinc, is then injected into the space between the parts. As the alloy cools it shrinks, forming a powerful mechanical lock.

Compared with other assembly techniques IMA offers many practical advantages. Perhaps the greatest is its ability to reduce costs by forming components as an integral part of the injected metal hub.

IMA, in short, is a great deal more than an assembly technique. It originated as an adaptation of die casting, and brings to the assembly process, the same benefits of consistent, predictable, low-cost precision manufacture.

This folder should start you thinking about Injected Metal Assembly and what it can do to improve your products and reduce your costs. Please call us; our technical representatives will be glad to contribute their experience to your search for an effective solution.

Circle 298

Joining

Not all joining methods require fasteners, and alternative methods are especially important for some materials.

A variety of methods join materials more or less directly, without the use of fasteners. These include adhesives, welding, brazing, and soldering. There are also specialized methods for joining without fasteners, such as clinching and injected-metal assembly. In addition, materials such as plastics, composites, and metal-ceramic combinations may indicate the use of certain joining methods.

Adhesives

Adhesives are often used as an alternative to mechanical fasteners. When using adhesives, however, the entire joint must be given even more consideration than when using mechanical fasteners. Unlike a bolt or rivet, an adhesive's properties may change depending on where it is used.

Functions: The main, though not the only, function of adhesives is to fasten parts together. Adhesives transmit stresses from one member of a joint to another with a more uniform distribution than conventional mechanical fasteners give. Consequently, adhesives often allow structures that are mechanically equivalent to, or stronger than, conventional assemblies to be built at lower cost and weight.

Epoxy adhesives commonly reach tensile adhesion values of 3,000 psi, comparable to a ½-in.-diameter spot weld every square inch, made in low-carbon steel.

Adhesively joined structures and products are inherently smooth. Exposed surfaces are not defaced, and contours are not disturbed as with other types of fastening systems. This is important both to function and appearance.

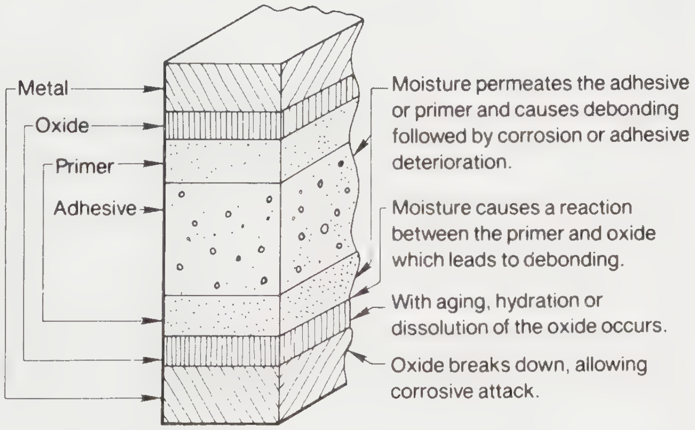
Light-gage materials are often good candidates for adhesive bonding, because the uniform stress distribution permits full use of the strength and rigidity of the adherends, without the distortion induced by other fastening methods.

Many adhesives easily join dissimilar materials, if proper surface treatments are used. Metal adherends that would ordinarily corrode because of their electromotive series relationship can be protected from corrosion by a layer of nonconductive adhesive that both joins and isolates them.

Adhesives also have an advantage where temperature variations are expected in the service of a product containing dissimilar materials. A flexible adhesive of adequate thickness can accommodate differences in thermal expansion among the adherends and prevent damage that might occur if a stiff fastening system were used.

Thermal-setting adhesives, such as epoxies and anaerobics, can be formulated to retain much of their strength over a broad temperature range, up to 300°F. Selecting a curing temperature close to the operating temperature can reduce the effect of thermal-expansion differences between materials.

FACTORS INFLUENCING BOND STABILITY


Metal
Oxide
Primer
Adhesive
Moisture permeates the adhesive or primer and causes debonding followed by corrosion or adhesive deterioration.
Moisture causes a reaction between the primer and oxide which leads to debonding.
With aging, hydration or dissolution of the oxide occurs.
Oxide breaks down, allowing corrosive attack.

Researchers at Wright-Patterson AFB have isolated a number of factors that cause adhesive bond failure.

Adhesive's continuous bond also seals against liquids or gases (provided they do not attack the adhesive). Some adhesives are used in place of solid or cellular gaskets. Adhesives are sometimes used with mechanical fasteners for sealing flange joints or holding the parts together while the bond forms.

Thin or fragile parts can be bonded. Adhesive joints do not usually impose heavy loads on the adherends, as in riveting, or localized heating, as in welding. The adherends will also be relatively free from heat distortion.

However, adhesives are not a joining cure-all. The very fact that so many adhesive formulations are available, for example, makes selecting the best adhesive for an application more difficult than choosing a mechanical fastening system. These variations also complicate control procedures on incoming materials, assembly processing, and testing of the finished product. Also, even though adhesive-bonding operations can be automated, they may require more highly skilled personnel than do other methods.

Structural or performance adhesives are load-bearing adhesives. That is, they add strength to the products being bonded. These adhesives are used to build things as varied as office furniture and automobiles. The seven most commonly used structural adhesives are:

- Epoxies
- Urethanes
- Cyanoacrylates
- Acrylics
- Anaerobics

- Hot melts
- Silicones

Epoxy adhesives are the oldest, most widely used structural adhesive. Offering the greatest shear strength — up to 10,000 psi — they can be modified to meet a variety of bonding needs. Generally, epoxy bonds are rigid; they fill gaps well with little shrinkage.

Epoxies, however, cure slowly (or require oven heating to speed the cure), operate well at temperatures only to 450°F, demand precise mixing equipment and are relatively brittle.

Acrylic adhesive formulations tolerate dirtier and less-prepared surfaces than other structural adhesives. They challenge epoxies in shear strength — up to 6,000 psi — and offer flexible bonds and superior peel and impact resistance.

Although acrylics are two-part adhesives, the resin is applied to one surface and an accelerator or primer to the other. The parts can be set aside for weeks with no detrimental effects. Once they are mated, handling strength is typically achieved in a few minutes. Curing can be completed at room temperature.

Acrylics, however, have a strong odor, are flammable, and have suffered from a lack of reproducible bonds in mass production.

Urethane adhesives bond permeable and impermeable materials. They are known for toughness (up to 2,200 psi) and flexibility even at low temperatures. Their shear strength can approach that of epoxies. They have excellent water and humidity resistance, but uncured urethanes are sensitive to moisture.

Anaerobic adhesives are single-component materials that are easily applied by hand or with automation. They are available in machinery and structural grades. Machinery grades offer high cohesive strength for cylindrical assemblies and a range of strength for threaded assemblies. Structural grades offer high tensile/shear strength for flat surface assemblies.

The basic cure mechanism is the deprivation of oxygen (hence the name "an-aerobic" — "without air"). However, this curing system can be combined with other cure mechanisms such as heat, primer, accelerator, and ultraviolet light for customized assembly-line treatments.

Anaerobic adhesives fill gaps up to 0.040 in. when properly engineered for viscosity and curing mechanism and are usually limited to service applications in the range of 300°F.

Cyanoacrylates vie with anaerobics for ease of curing and adaptability to assembly-line production. The original materials had low viscosity, exhibited poor impact and heat resistance, and were vulnerable to moisture and solvents. Modern elastomer-modified cyanoacrylates offer new ranges of toughness, viscosity (up to gel grades), and resistance to moisture, solvents, and heat. The modified types bond virtually any surfaces and have better handling characteristics due to slower cure times.

The original materials are still among the most widely used bonding materials. They cure in seconds at room temperature due to their reaction to trace levels of moisture on most surfaces. These adhesives have variable viscosities and excellent tensile strength.

Hot melts have moved out of their traditional applications into areas of low-stress product assemblies — even of metals. They form flexible and rigid bonds, achieve 80% of bond strength within seconds, bond permeable and impermeable materials and usually require no elaborate surface preparation. Hot melts are insensitive to moisture and most solvents, but they soften at high temperatures.

Silicone adhesives have one component and cure at room temperature. They are readily dispensed by hand or automation. Their operating temperature range is essentially unequalled and is particularly unmatched on the high end. Service life for these adhesives is very long, and they have excellent resistance to UV and ozone attack. Silicones' gap-filling capabilities make them ideal sealants in many applications.

Cure occurs when the silicone is dispensed and comes in contact with the moisture in the air. Drawbacks include some rather long cure times and relatively high material costs. Tensile and shear strengths tend to be rather low. However, peel strength and impact resistance are good.

Adhesive selection: Selecting the proper adhesive involves consideration of:

- Manufacturing conditions
- Substrates to be bonded
- End-use environment
- Cost factors

Manufacturing conditions include machinery, material-handling methods, and plant conditions.

Machinery: The design engineer should determine what machinery is already in place at the manufacturing facility. The engineer may recommend the appropriate applicators for the type of adhesive required. Spray and extrusion applicators are excellent for applying low-viscosity fluid adhesive products. Roller applicators normally apply medium-viscosity adhesives. Pot applicators are suited to a high viscosity.

Material-handling methods: Machinery is not limited to applicators. The manufacturer's materials handling also is important. For example, how much time does the manufacturing process allow for bonding? Does product handling require the initial bond strength to be greater than normally needed? Is there time for a product which bonds more slowly?

Plant conditions: Manufacturing conditions involve more than the machinery and material-handling methods in the plant. Plant conditions such as the condition of the equipment and the skill of the product personnel should also be considered.

Substrates to be bonded: The openness, or porosity, of the substrate to be bonded can place additional demands on an adhesive system. Excessive penetration, hardness or impenetrability can make some adhesives unsuitable.

Adhesion to a coated surface such as painted or plated steel must take into account the surface coating, not only the base substrate. The coating has a profound effect on whether or not certain adhesive systems will be suitable for use in that application.

End-use environment: The end-use environment includes all conditions to which the adhesive bond will be subjected during the useful life of the finished product. Considerations vary from application to application and include stress, the kind of joint being used, temperatures, exposure to moisture, flexibility, age, stability, and aesthetics.

Stresses: These include stress placed on the glue line during construction as well as end-use stress — the conditions the construction will be expected to encounter.

There are four types of stress:

- Shear, generated when the adherends move in parallel planes.
- Tension, generated when the adherends are pulled apart in the same plane.
- Cleavage, when two adherends are pried apart at the end of a lap joint.
- Peel, an exaggerated form of cleavage that occurs when a flexible adherend is bent away from the bond line.

There are three bonding failure types:

- Adhesive: the adhesive peels off the substrate surface.
- Cohesive: the adhesive sticks to

the substrate surface but rips itself apart.

- Delamination: the adhesive sticks together, and to the substrate surface, but pulls the coating off the metal.

Joints: There are many different kinds of joints including butt, lap, beveled lap, scarf lap, and inert-T.

Generally, adhesive-bonded joints in load-bearing structures should be loaded essentially in shear, minimizing the stress induced by peel, cleavage, and impact forces.

Joints must be designed specifically for adhesive bonding; seldom can an assembly designed for another method of fastening be successfully bonded without being modified. Adhesively bonded joints must be stressed in their strongest directions — in tension, shear, and compression — and load must be minimized in peel and cleavage directions.

Temperature: The adhesive and the substrate can become brittle due to low temperatures, or may melt or decompose under conditions of extreme heat.

Heat sensitivity of adhesives is an important consideration in their selection and can be one of their most severe limitations. While some can withstand temperatures as high as 700°F, most are limited to service under 200°F. Most high-temperature adhesives require an oven cure, although some cure at room temperature. If an adhesive is not formulated for high-temperature service, its strength drops considerably in such environments. Low temperatures, on the other hand, make many adhesives brittle and stress joints internally.

Harsh exposure: Consider water and humidity, as well as exposure to solvents and such.

Other items include flexibility, aging stability, and aesthetic questions such as what are the joint's flexibility requirements? And its life span? What color is required and what level of gloss?

Cost factors relate the cost of the adhesive bonding process to other values in the manufacturing process.

If several adhesive systems meet the requirements for an application but significantly differ in price, more detailed analysis could determine an actual bonding cost per unit. Criteria involved include waste, process speed, rejects/failures, packaging, reliability, availability, and service.

Waste: Waste increases the cost per bond and the impact on the machinery. Cleaner application characteristics lead to less downtime and increased use of production equipment.

Process speed: If one adhesive provides faster production speeds than the others, that value should be included in the cost/value ratio.

Rejects and field failures: Rejects are a fact of life, and usually an acceptable level of rejection has been established. If an adhesive system offers performance properties that reduce reject rates, higher initial costs can be overcome, and profits may increase.

By figuring the costs surrounding packaging considerations — product consistency, batch-to-batch reliability, product availability and the strength of the supplier's backup service — the total cost of each contending adhesive presents itself.

Adhesive application: Adhesives can be applied with any type of liquid-handling tool such as a brush, spatula, trowel, dip, spray, curtain, flow gun, or flow brush. However, production-line conditions generally require use of automatic or semiautomatic dispensing equipment which can apply dots, bands, or beads. Most serious designers will not consider an adhesive without also considering a suitable application method.

Dip coating and spraying can also be used for flat parts, but are especially suitable for contoured parts. Brushing is widely used to apply liquid and thin-paste adhesive: Equipment is simple, waste is minimal, and limited areas of contoured shapes can be coated without masking. However, high production rates and uniform adhesive thicknesses are difficult to achieve.

Surface preparation: Proper surface preparation is essential for achieving good bond strength with any adhesive. The extent of preparation depends on the type of substrate, the chemical nature of the adhesive, and the bond strength required. In general, the higher the desired strength, the more complex the prebond treatment.

Prebond treatments consist of cleaning, abrading, and/or chemical altering of the surfaces. At the minimum, all surfaces must be clean. This means removing oil, grease, rust, scale, and mold releases by solvent, chemical, or abrasive means. For parts subjected to mild environmental conditions and moderate loads, a simple cleaning may be all that is required. However, for critical applications, it is usually necessary to chemically alter the substrate surface to form an intermediate molecular layer with a higher chemical affinity for the adhesive being used. Bond strength and reliability are significantly increased, especially in abusive environments.

Metals: A solvent wipe or vapor degreasing is adequate for many non-critical applications. However, for highest strengths and long-term reliability, a chemical treatment is required. The treatment differs for each metal, but all require strong oxidizing solutions which chemically create a tightly bound surface layer of metallic oxide. Most adhesives will bond to such layers with much higher strengths than to the pure metal surfaces.

Ceramics and glasses: Chemical surface treatments are not normally required for these materials. A solvent or detergent cleaning is usually sufficient.

Thermoplastic materials: Most thermoplastics can be successfully bonded with adhesives. However, the type of adhesive chosen depends on the chemical nature of the plastic. For example, polystyrene is easily bonded with solvent adhesives, polyethylene can be joined with hot melts, and flexible PVC bonds well with cyanoacrylates.

All thermoplastic materials first require a thorough cleaning and light abrading of the surface. Mold-release agents, lubricants, and plasticizers are generally present on plastic surfaces and will prevent proper wetting by the adhesive if not removed.

Thermoset materials: Epoxy, phenolic, polyester, silicone, and diallyl phthalate usually need only a solvent cleaning and light abrasion to remove fingerprints, mold releases, and other normal contaminants. Careful selection of the proper adhesive for each substrate is essential, however, for successful bonds.

Mechanical surface abrasion, such as sanding or sand blasting, is sometimes the best way to prepare a surface. This method not only cleans the surface, but roughens it, which often improves the bond. Anaerobics, for example, when used in threaded assemblies, rely on the interlocking of microscopic surface roughness for their bonding action.

Surface preparation may be totally avoided if an acrylic adhesive, based on reactive-fluid technology, is used. The adhesive has components that cut through surface film and bond to the metal directly. A primer is first applied to the parts to be joined, then the adhesive is added and the parts are pressed together.

Pressure-sensitive adhesive tapes: Rubber and acrylic-based pressure-sensitive adhesive tapes are common for industrial fastening. Silicone tapes are also used in special applications. Selection of an adhesive tape requires knowledge of what types of surfaces will be fastened and the forces and environments to be encountered.

Rubber-based tapes are used

where no temperature extremes are encountered. They build up to final bond strength in a short period of time. Rubber-based tapes are very suitable for temporary holding applications such as mounting rubber and photopolymer plates that are removed after a production run; other tapes may be used for permanent applications such as mounting hooks and appliance trim. Rubber-based tapes offer better initial adhesion than most acrylics and have better long-term adhesion to materials with low surface energy, such as polyethylene and polypropylene.

Characteristics of soft and firm adhesive tapes

	Soft	Firm
Initial adhesion	High	Low
Ultimate bond	Good	High
Suitable substrates	Many	Few
Rubdown pressure	Low	Firm
Temperature resistance	Good	Excellent
Shear and holding strength	Good	Very good
Solvent resistance	Good	Excellent
Removability	Good	Poor

Characteristics of rubber and acrylic adhesive tapes

	Rubber	Acrylic
Initial adhesion	High	Fair
Adhesion buildup	Some	Excellent
Shear strength	Good	High
Temperature resistance	Moderate	High
Solvent resistance	Good	Excellent
UV resistance	Fair	Excellent
Life	Moderate	Excellent

Acrylic adhesives retain adhesion over a large temperature range, resist moisture and ultraviolet light better than rubber-based types, and are easier to apply.

Acrylic adhesives come in two basic types. In one, a foam carrier is coated with acrylic adhesive on both sides; a protective layer of liner material separates the tape layers and is peeled off in use. The second type has no carrier, just a thin film of pressure-sensitive acrylic adhesive that is captive between one or two siliconized release liners.

Foam tapes are used where there may be relative movement between the surfaces, or where static but irregular surfaces must be joined. The foam fills in the irregularities, improving adhesive contact.

Transfer adhesive tapes, those without carriers, are used where one or both of two surfaces are flexible and both surfaces are relatively smooth. These products provide a thin adhesive profile and are used where the finished appearance is important. Transfer tapes usually have a 0.001 to 0.002-in. thickness. After the tape has been applied to one surface, the protective liner is peeled away, exposing the adhesive for attachment to the second surface.

Silicone pressure-sensitive adhesives exhibit exceptional temperature resistance, from −100 to 500°F, without becoming brittle or soft. This range is nearly double that of conventional acrylic adhesives (−50 to 250°F). Like rubber-based adhesives, silicones adhere well to a variety of both low and high-energy surfaces and are chemically inert.

Silicone adhesive products are usually provided in two forms. Coated on a polymeric film such as polyester or Kapton, silicones are used for splicing, masking, or sealing. Silicones also act as a transfer adhesive for more demanding applications where an acrylic transfer film will not offer the desired adhesion or stable temperatures.

Welding

Welding allows parts to coalesce along their contacting surfaces by applying heat, pressure, or both, and often adding a filler material. The most common industrial welding methods are fusion processes in which workpieces are melted at their common surfaces.

Solid-state welding joins parts through the application of heat and pressure. The temperature is usually below the melting point of the materials joined. Hot-press, ultrasonic, diffusion, and explosive welding are examples of solid-state welding.

Fusion-welding methods, chiefly gas, arc, and resistance, are the most widely used and are less restrictive as to the materials that can be joined. Diffusion welding is employed primarily in the aerospace industry to join high-strength materials.

Arc welding: In arc welding, an arc between an electrode and the workpiece generates heat. Shielding the molten weld metal from the atmosphere with gases fed in or generated by the weld reaction is often critical. Reaction of unwanted gases with the molten metal causes strength-reducing oxides and inclusions within the weld. Arc-welding processes vary mainly in the way the weld is shielded and the methods of applying filler material.

Shielded-metal arc welding (SMAW): This form of welding, also called stick welding, is usually done manually, with the welder feeding a consumable, coated electrode in the work area. The flux coating provides arc stabilizers; gases to displace air; metal; and slag to protect, support, and insulate the weld metal. Many electrode and flux coatings are available that are matched to type, size, and position of the material welded.

SMAW is suitable for portable applications. Its labor and material costs are high, but its simplicity and versatility make it the most commonly used welding process.

Gas-metal arc welding (GMAW): This process generates an arc between a consumable electrode wire and the workpiece. Shielding is provided by gas which flows over the weld area from the welding gun. Combinations of shielding gas, power source, and electrode have significant effects on the mode of metal transfer across the arc. A variety of gases are used, depending on the reactivity of the metal and the design of the joint. For example, argon is used most often, though carbon dioxide is added when welding ferrous metals. Carbon dioxide is sometimes used alone to shield steels. GMAW processes are fast and can be automated. They work in all positions.

Flux-core arc welding (FCAW): This process is very similar to gas-metal arc welding. Weld heat is produced from an arc between the work and a continuously fed filler-metal electrode. The electrode is hollow with flux in the core. The core may provide shielding gases, deoxidizers, and slag-forming materials. In some cases, materials may be added to promote arc stability, enhance weld-metal properties, and improve weld contour. FCAW is used only on ferrous metals, chiefly mild and low-alloy steels. Some FCAW electrodes are self-shielding, but others require an external shielding gas, usually carbon dioxide. If extra shielding is needed it is supplied through a nozzle. This process works in all positions, producing a fast, clean weld. Both GMAW and FCAW are sometimes referred to as MIG welding. They require less skill than SMAW.

Gas-tungsten arc welding (GTAW): In GTAW, an arc is generated between a nonconsumable tungsten electrode and the work areas. Wire filler metal is fed in separately. Work is shielded by helium or argon gas. The process, also called TIG (tungsten inert-gas welding), is more expensive than GMAW, but is used on thinner metals such as aluminum, magnesium, titanium, and high-alloy steels.

GTAW may use dc or ac. When ac is used with argon shielding, arc cleaning action is produced at aluminum and magnesium joint surfaces. This removes oxides and is useful in removing porosity in aluminum. Helium used with dc provides deeper penetration, but requires stringent cleaning of aluminum and magnesium. Ac is preferred for aluminum and magnesium.

GTAW costs more than SMAW and is much slower than GMAW, but it provides a high-quality weld in a very wide range of thicknesses, positions, and geometries. The process can be fully automated.

Comparing welding methods

Characteristics	Laser	Electron beam	Resistance spot	Gas-tungsten arc
Heat generation	Low	Moderate	Moderate	Very high
Weld quality	Excellent	Excellent	Good	Excellent
Weld speed	Moderate	High	Moderate	High
Initial costs	Moderate	High	Low	Low
Operating/ maintenance costs	Low	Moderate	Low	Low
Tooling costs	Low	High	High	Moderate
Controllability	Very good	Good	Low	Fair
Ease of automation	Excellent	Good	Fair	Fair
Range of dissimilar materials	Very wide	Wide	Narrow	Narrow

Source: *Metals Joining Manual, McGraw-Hill Co., 1979.*

Submerged arc welding (SAW): Heat is produced from an arc between the work and a continuously fed filler-metal electrode. The molten weld puddle is protected from the surrounding atmosphere by a blanket of granular fluxing material preplaced on the work. The process is limited to flat, or nearly flat, workpieces. Both flux and filler wire can be fed automatically, and the process is most commonly used in mechanized operations.

Plasma arc welding (PAW): Hot ionized gases shield the work area in this process. The plasma is sometimes supplemented with a separate shielding gas. The welding gun is similar to that used with GTAW in that it has a nonconsumable tungsten electrode. Filler material, if used, is fed in separately. The weld produced is also similar to GTAW, but the process is much faster and arc control is superior. Plasma arc welding produces a deep, narrow, uniform beam and is suitable for refractory metals, low-alloy steels, stainless steels, aluminum, and titanium. It is most frequently used for high-quality welds on high-strength, thin-section material. The process has the advantage of tolerating great variations in joint alignment. It also does not generate a high-frequency arc.

Resistance welding: Resistance welding is a process where coalescence is produced by heat obtained from the resistance of the workpiece to the flow of electric current through the parts being joined. Heat is developed in the assembly to be welded, and pressure is applied by the welding machine through the electrodes. Fluxes or filler metals are not needed.

The process is commonly used as a mass-production technique requiring special fixtures and automatic handling equipment. Resistance welding can be applied to almost all steels and aluminum alloys and some dissimilar metal bonds. Heating is localized. Common stock thickness range is 0.004 to 0.75 in.

The process may be continuous, as when welding pipe seams, or finite, as in spot welding. There are no limitations on welding position. This process works well with robotics.

Percussive arc welding: This technique can be considered a special case of dc resistance welding. In percussive arc welding, power is usually supplied by a capacitor bank that is directly short-circuited across the parts to be welded. The full charge of the capacitor bank is concentrated at the point where the electrode nib comes in contact with the part. The nib vaporizes, establishing an ionized area. This provides a localized arc for the remaining capacitor charge that puddles an area on the surface of both the parts.

The weld head moves forward quickly before the materials solidify. This forces an alloying of the interface to produce an excellent low-penetration, low heat-affected-zone weld, usually having excellent character and grain structure. Percussive arc welding is most commonly used for stud welding of precision parts.

However, the process is sensitive to humidity. Moist air tends to destroy process consistency. Also, large welds tend to be very noisy, with a loud percussive repeat which gives the process its name. The process is also relatively slow because of the time required to recharge the capacitor bank.

Oxyfuel gas welding (OFW): This group of welding processes uses the heat produced by a gas flame to melt the base metal (and the filler metal, when used). Various fuel-gas combinations are burned in oxygen to produce the necessary heat. Oxygen and acetylene is the most commonly used combination. The mixture produces a temperature of around 5,600°F. Oxy-acetylene torches can be used with or without a filler metal.

Because OFW requires minimal equipment, it is inexpensive and suitable for manual methods. However, it is slow.

Specialty systems: These include:

Electron-beam welding (EBW): EBW uses energy from a fast-moving beam of electrons focused on the base material. The electrons strike the metal surface, giving up their kinetic energy almost completely in the form of heat. Welds are made in a vacuum, which eliminates contamination of the weld material by the gases left in the vacuum chamber. The high vacuum produces a stable beam.

With high beam energy, a hole can be melted through the material. This hole is moved along the joint by moving either the electron gun or the workpiece, and is maintained as the metal at the front melts and flows around to the rear, where it solidifies. Welds can be made without a hole, where melting takes place by conduction of heat from the surface, but such welds are slower.

EBW can produce deep, narrow, almost parallel-sided welds with low total heat input and relatively narrow heat-affected zones. The depth-to-width ratio can be as high as 30:1 in some cases. The low energy input allows welding close to heat-sensitive components. Also, projecting the electron beam makes it possible to weld in otherwise inaccessible locations.

Though equipment costs are high, indirect cost savings can result from reduced joint-preparation costs, ability to weld in a single pass, high welding speed, and low distortion. However, the process can only be used to produce a tight butt or lap joint.

Laser-beam welding (LBW): Fusion is obtained by directing a concentrated beam of coherent light to a very small spot. Laser beams combine low heat input with an intensity greater than the electron beam. Since the heat is provided by a beam of light, there is no physical contact between the workpiece and welding equipment. Welds can be made through transparent materials.

LBW is flexible because the laser

beam can be moved under digital control to seam weld any shape. Laser welding plays an important role in microelectronics and light-gage metal-welding applications that require precise welding control.

LBW can be used with a variety of metals, including low-alloy and stainless steels, aluminum alloys, lead, titanium, refractory metals, and high-temperature alloys. It vaporizes the metal at the laser's point of focus, producing a deep penetration column of vapor. The vapor column is surrounded by a liquid pool, which is moved along the joint to produce welds with depth-to-width ratios greater than 8:1. However, speeds may be low in seam welding because the welds actually consist of a series of overlapping spot welds.

Electroslag welding (ESW): Heat for ESW is provided by an electrically conductive molten slag that is resistance heated by the welding current. Electrodes are fed continuously into this molten pool of slag at a temperature in excess of 3,200°F.

Electroslag welding is suitable for welding joints in thick metal plates because the weld pool is confined and molded by copper dams. However, electroslag welds must be completed in one continuous process. Restarting a weld after a stop can result in a large discontinuity. ESW tends to produce a large grain size because of the large mass of metal that is molten at a given time, and the slow cooling of the metal.

Solid-state welding: These techniques include:

Inertia welding: This is one of the few solid-state welding processes that have been generally accepted by industry. Kinetic energy, stored in a flywheel, is converted to heat by friction between the workpieces. One part to be joined is fixed; the other is clamped in a spindle chuck. The flywheel (to which the movable part is attached) is accelerated and, at a predetermined speed, driving power is cut and the parts are forced together.

The major limitation of the process is that one of the two parts to be joined must be axially symmetric. But inertia welding has few of the limitations regarding materials and part cleanliness of some of the other solid-state welding techniques.

The advantages of inertia welding include:

- Superior weld
- Fast, uniform production welds
- Clean operation
- Low energy costs
- Minimum labor skill
- The amount of upset of parts can be controlled to close tolerances.
- A complete interface weld can be obtained.

Soldering processes

Soldering uses alloys that melt under 840°F to join metals. Molten solder fills the space between surfaces to be joined, adheres to the surfaces, and solidifies.

Soldering is frequently used for electrical and electronic applications, which account for almost half of all soldering applications. Sealing, such as tin-can and radiator seams, is the second most common use.

Automated soldering equipment produces high-quality joints at a relatively low cost per joint.

Conditions for choosing a heating method involve:

- Cost of providing the heat to bring an assembly to soldering temperature.
- Efficiency in bringing joint to soldering temperature.
- Sensitivity of the assembly to heat.
- Ability to automate.

Solder alloys: The largest group of soldering alloys is tin-lead alloys. These solders are compatible with all base-metal cleaners, fluxes, and heating methods, and can join most metals. Joint clearances of 0.002 ± 0.0005 in. are recommended.

Tin-lead-antimony alloys are used for the same types of applications as tin-lead solders. They are not recommended for use on aluminum, zinc, or galvanized steel. Addition of antimony (up to a maximum of 6%) in place of some of the tin improves strength and does not affect wettability or flow characteristics. Joint-clearance recommendations are the same as tin-lead solders.

Tin-antimony solder (95% tin) has the best electrical properties of any common solder alloy. It has high strength at temperatures up to 300°F, and excellent flow characteristics.

Tin-silver alloys have the same characteristics as tin-antimony solders and are used for delicate instrument work and high-strength applications.

Tin-zinc alloys are used mainly for soldering aluminum — primarily where a low soldering temperature is required.

Lead-silver solders have high tensile, creep, and shear strengths to 350°F. Fatigue properties are better than those of nonsilver solder alloys. The lead-silver solders have poor wetting characteristics, however, and corrode in humid atmospheres. The addition of 1% tin, replacing silver, increases wetting and flow, and reduces susceptibility to corrosion. When tin is added, silver content should be limited to 1.5% to avoid segregation.

Cadmium-zinc solders are used to join aluminum to itself and to other metals. They are suitable for applications where service temperatures may reach 400°F or higher.

Zinc-aluminum solders are specifically designed for soldering aluminum. They provide high joint strength and good corrosion resistance. A 95% zinc/5% aluminum solder is used without flux for ultrasonic soldering of heat exchangers.

Indium solders are used for special applications, such as cryogenic products. The 50% indium/50% tin alloy is suitable for glass-to-glass and glass-to-metal soldering.

Fusible alloys are bismuth-containing solders, used where soldering must be done at temperatures below 361°F. These solders creep during longtime loading above room temperature. Higher-bismuth-content solders are not easily adaptable to high-speed soldering operations, nor do they easily wet base metals.

Nonferrous materials: Most nonferrous metals and their alloys can be soldered. Some require special solders or fluxes and carefully controlled production methods.

Aluminum soldering differs from other common metals in several ways. Aluminum forms a tenacious, refractory oxide; therefore, use of reaction fluxes is mandatory — except for ultrasonic soldering.

Aluminum soldering requires special techniques to produce flow into certain joints. Solder composition is more important with aluminum than with many other metals, because galvanic corrosion can cause catastrophic failure.

Solders with high zinc content are used on wrought-aluminum assemblies. Tin-lead solders are not recommended because of poor corrosion resistance.

Copper is one of the easiest metals to solder. Nearly all solders and fluxes can be used — the choice depends primarily on the application.

Most copper-base alloys have good solderability. However, alloys containing beryllium, silicon, or aluminum require acid fluxes. Also, copper-zinc alloys (brasses) should not be soldered with tin-antimony or tin-lead-antimony solders containing more than 1% antimony or 0.02% arsenic.

Nickel and high-nickel alloys can be soldered either to themselves or to other solderable metals. Pure nickel and such alloys as Monel, K Monel,

Carr Lane's Complete Line

of TOOLING COMPONENTS for JIGS and FIXTURES

SWIFTSURE

Power Workholding

SWING CLAMPS

WORK SUPPORTS

NEED TOGGLE CLAMPS?
See our Newly Expanded Line of Toggle Clamps in our complete Illustrated Catalog.

And don't forget about these newly revised and updated catalogs, with huge selections available.

TOOLING COMPONENT CATALOG
with Metric & U.S. sizes

DRILL BUSHINGS

NEW ITEMS

SERRATED ADJUSTABLE CLAMPS (MINI AND EXTRA LARGE)
HAND-RETRACTABLE PLUNGERS (NOW IN STAINLESS)
LEVELING FEET (NEW LARGE SIZES)
TOGGLE CLAMPS (18 NEW MODELS)

Carr Lane's Patented Items

For your additional convenience Toggle Clamps, Modular Fixturing and Drill Bushings are listed separately in the Complete Line Catalog.

SEND REPLY CARD TODAY!

For your ***FREE*** Copy of Carr Lane's Latest Complete Line Catalog.

PLACE STAMP HERE

Carr Lane MANUFACTURING CO.
4200 Carr Lane Ct., P.O. Box 191970
St. Louis, Missouri 63119-2196

Carr Lane®

PRINTED IN U.S.A.

CIRCLE 90 on reader information card

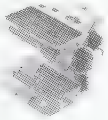
MD1992

Carr Lane

is interested in you, your ideas and needs!

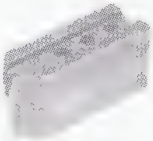
KEENSERT ASSORTMENTS

POWER TOGGLE CLAMPS

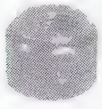

LIFT-N-C JIGS

ROUND & DIAMOND PINS

HAND RETRACTABLE PLUNGERS

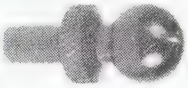

CHUCK JAWS

PLASTIC C CLAMPS


QUICK-ACTING KNURLED KNOBS

PLASTIC KNOBS

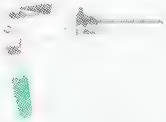
HAND KNOB ASSEMBLIES


TOOLING BALLS

CONE LOCATORS

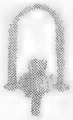
DRILL BUSHINGS

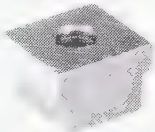
LOCATOR-NOSE CLAMP STRAPS

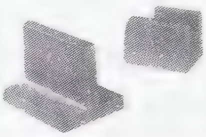

TOGGLE CLAMPS

STEP BLOCKS AND CLAMPS

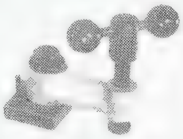
HAND WHEELS

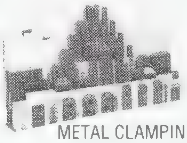

SWIVEL HOIST RINGS

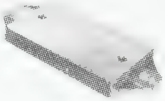

STEP FIXTURE KEYS



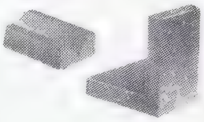
LEVELING FEET


SWING CLAMP ASSEMBLIES


METAL CLAMPING KIT HOLDERS


MILL FIXTURE BASES

SPRING STOP BUTTONS


CAST SECTIONS-ANGLE, SQUARE, T, U, V

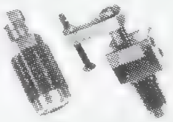
QUICK-RELEASE PINS

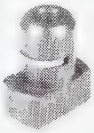
SLOTTED-HEEL CLAMP ASSEMBLIES

MODULAR FIXTURING

BULLET NOSE DOWELS

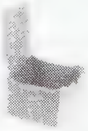
LATCH ACTION CLAMPS

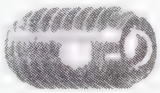

POWER WORKHOLDING DEVICES

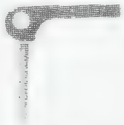

SURE LOCK FIXTURE KEYS

BAR KNOBS

FERRULES


TUMBLE BOX JIGS


SPRING/BALL PLUNGERS


EXPANDING PINS

*Yes! Please send me my **FREE** catalog of Carr Lane's tooling components.*

☐ Complete Line Catalog

Individual catalogs (contained in the above catalog).

- ☐ Modular Fixturing Catalog
- ☐ Toggle Clamp Catalog
- ☐ Drill Bushing Catalog
- ☐ ***SWIFTSURE*** Power Workholding Catalog

☐ CAD/CAM Information

☐ Handy Multiplier and Trig Book

☐ Modular Fixturing Textbook ($12.00 each + $ 2.50 Shipping & Handling

Templates

- ☐ Tooling Component Templates
- ☐ Modular Fixturing Templates
- ☐ Toggle Clamp Templates
- ☐ ***SWIFTSURE*** Templates

Name ______________________ Title ______________

Company ______________________

Address ______________________

City ______________________ State ________ Zip ________

Phone (   ) ______________

Carr Lane MANUFACTURING CO.
4200 Carr Lane Ct. P.O. Box 191970
St. Louis, Missouri 63119-2196
Phone: 314-647-6200, FAX: 314-647-5736

CAD/CAM

SPECIAL OFFER

Carr Lane's Tool Designer's Assistant® saves engineers countless hours of design time, with a 2-D and 3-D library of more than 7200 tooling components. Available in a wide variety of software formats. And now, for a limited time, Carr Lane has an offer you won't want to miss. Send for details today!

Carr Lane

Permanickel, and Duranickel are solderable with inorganic fluxes. Alloys such as Inconel, Incoloy, Inconel X, and Nimonic 75 are difficult to solder.

Age-hardenable materials should be soldered after aging. The temperature involved in soldering will not soften such metals as Duranickel, K Monel, and Inconel X, which have been fully age hardened.

Relatively high-tin solders such as 60% tin/40% lead or 50% tin/50% lead are used for joining high-nickel alloys.

Zinc soldering is not difficult. Zinc-chloride fluxes containing some hydrochloric acid are generally used. Zinc die castings normally contain aluminum and other alloys which make them very difficult to solder. These must be treated as though they were an aluminum alloy.

Ferrous materials: Solderability of steel is influenced by its alloying constituents. Low-alloy or mild steels are most easily soldered. Mildly corrosive fluxes are necessary. Medium-carbon steels (0.30 to 0.45% C) solder less readily than low-carbon steels (0.30% C or less). Consequently, surface preparation is more critical.

High-carbon steels (over 0.45% C) are seldom soldered. A hot alkaline cleaner, followed by an acid dip, generally produces good soldering surfaces. To facilitate fabrication, these metals can be precoated with solder to provide corrosion protection and improve onsite joining.

Stainless steels can be joined by commercially available lead-tin solders, but corrosive stainless-steel fluxes must be used. If the soldered joint is inaccessible and flux cannot be removed after assembly, pretinning of parts is imperative. Cast iron should not be soldered.

In the case of critical applications, including those for nuclear products, designers should make sure there are no detrimental reactions between the base metals and the solder used.

Brazing processes

Brazing joins parts by heating them to more than 840°F and applying a filler metal that has a melting temperature below that of the base metal. Filler metal flows into the joint by capillary attraction.

Some advantages of brazing are:

- Dissimilar metals can be joined.
- Assemblies can be brazed in a stress-free condition.
- Complex assemblies can be brazed in several steps by using filler metals with progressively lower melting temperatures.
- Materials of different thicknesses can be joined.
- Cast and wrought metals can be joined.
- Nonmetals can be joined to metals when the nonmetal is coated.
- Metallurgical properties of base materials are not seriously disturbed.
- Brazed joints require little or no finishing.

Brazing is typically done with a torch or in a furnace. Other methods include dip, resistance, and induction brazing.

Torch brazing joins relatively small assemblies made from materials that do not oxidize at the brazing temperature or can be protected from oxidation with a flux. The most commonly used filler metals include: aluminum-silicon alloys, silver-base alloys, and copper-zinc alloys. A flux is required with these filler metals if a protective atmosphere is not used. Self-fluxing copper-phosphorus alloys are also used. Torch brazing is done in air and is the most common brazing process.

Normally, torch brazing is done with handheld oxyfuel gas torches using various fuels. However, there are automated machines that use preplaced fluxes as well as preplaced filler metal in paste, wire, or shim form. Torch and machine brazing are generally used to make lap joints in sections from 0.01 to 0.25 in. thick. Joints can be brazed rapidly, but speed decreases as material thickness increases.

Furnace brazing is practical if the product is self-jigging or can be preassembled and placed in a jig; if brazing material can be placed in contact with the joint; and if the part can survive uniform heating. Furnace brazing is suited for fabricating complete brazements, although it does not require a highly skilled operator. Prefluxed or precleaned parts with filler metal preplaced at the joints are heated in furnaces. Brazing can be done in an air furnace with a flux, though a protective atmosphere is usually needed. The type of atmosphere required depends upon the materials being brazed and the filler metals being used.

Base metals with readily reducible oxides can be brazed in an atmosphere of combusted natural gas or cracked ammonia. Dry hydrogen, a powerful reducing agent, can be used for brazing most stainless steels and many of the nickel, cobalt, and iron-base alloys.

Heat-resistant, high-strength alloys that contain appreciable amounts of aluminum or titanium are frequently brazed in a vacuum to prevent formation of oxides that inhibit wetting and flow of the filler metal. Parts made from such base metals can be plated to prevent oxidation during brazing.

BRAZING SAFETY

The possibility of dangerous fumes arising from cadmium-bearing base or filler metals, and from fluorides in fluxes always exists in brazing. Precautions should be followed to guard against any hazard from these fumes. Also consult American National Standard Z49.1, "Safety in Welding and Cutting," published by the American Welding Society (AWS).

1. ***Ventilate confined areas.*** Install ventilating fans and exhaust hoods to carry fumes away from work, or use air-supplied respirators as required.
2. ***Clean base metals thoroughly.*** A surface contaminant of unknown composition on base metals may add to fume hazard and may cause a too-rapid breakdown of flux, leading to overheating and fuming.
3. ***Use sufficient flux.*** Flux protects base metals and filler metal from oxidation during the heating cycle. Full flux coverage reduces the chance of fumes.
4. ***Heat metals broadly.*** Heat the base metals broadly and uniformly. Intense localized heating uses up flux and increases danger of fuming. Apply heat only to base metals, not to filler metal. (Direct flame on filler metal causes overheating and fuming.)
5. ***Know your base metals.*** A cadmium coating on a base metal will oxidize to a toxic fume during heating. Zinc coatings (galvanized) will also fume when heated. Learn to recognize these platings. It is recommended that they be removed before parts are heated for brazing.
6. ***Know your filler metals.*** Be careful not to overheat the assembly when using filler metals that contain cadmium. These filler metals are subject to toxic fuming if overheated. Cadmium-bearing filler metals carry a warning notice that should be read, and instructions should be followed carefully.

Copyright, 1977, by Handy & Harman. Reprinted from The Brazing Book with permission.

Plated parts can be brazed in a vacuum or in a controlled atmosphere.

Dip brazing is used to braze aluminum assemblies because the temperature of the molten flux bath can be controlled. The molten bath serves as both the heating medium and the fluxing agent. Uniform heating to brazing temperature is achieved rapidly. Parts are cleaned, assembled, and held together in fixtures during brazing. Parts are normally preheated before immersion. Residues must be removed after brazing in order to prevent corrosion.

Production rates and efficiency are good, heating rates are very fast, and many joints can be brazed at once. However, molten-metal baths are limited to use on small (0.005 to 0.200-in.) wires, sheet, and fittings that can be dipped into small heated pots.

Induction brazing heats the workpiece by inducing a high-frequency current in the metal. The technique is used when the entire assembly must be heated or when part of the assembly would be adversely affected by heat. Because the workpiece is heated selectively by the coil, induction brazing reduces unwanted part distortion or annealing. Induction heating is a rapid way to bring the joint to brazing temperature.

Brazeable metals: Low-carbon and low-alloy steels are brazed readily with silver or copper-base filler metals. Nickel-base alloys are sometimes used for applications requiring greater corrosion resistance or higher joint strength.

For some hardenable low-alloy steels, the recommended heat treatment must be considered in selecting the filler metal. Sometimes filler metal can be selected so that brazing and heat-treating operations are combined. Decarburization and grain growth may occur in low-alloy steels if they are overheated during brazing. Therefore, short brazing cycles should be used.

Stainless steels can be brazed in a dry hydrogen atmosphere or in a vacuum. Atmosphere dewpoint must be maintained at −60°F or lower to prevent formation of chromium oxide. At moderate brazing temperatures, stainless steels can be torch brazed in air if flux is used.

Austenitic alloys (nonhardenable AISI 200 and 300-series stainless steels) are well suited for brazing. Type 200 stainless steels can be torch or furnace brazed with silver, copper, or nickel-base filler metals. Furnace brazing above 1,400°F is usually done in a dry hydrogen atmosphere. In brazing the unstabilized grades such as Types 302 and 304, carbide precipitation may occur in the grain boundaries if the assembly is held too long at temperatures between 800 and 1,500°F. This problem is not present when the stabilized grades (Types 321 and 347) or the low-carbon 300-series varieties such as 304L and 316L are brazed.

Type 200 stainless steels can be brazed in a hydrogen atmosphere, if a very low dewpoint is maintained to prevent formation of manganese oxide, which reduces wettability. Chromium-nickel steels must not be stressed during brazing to avoid cracking.

Ferritic stainless steels may present a problem with interfacial corrosion when torch brazed with some silver-base alloys and flux. This corrosion can be prevented by using silver-base filler metals containing small amounts of nickel.

Martensitic stainless steels are easily brazed. Filler metal must be selected so the brazing cycle is compatible with the required heat treatment. These steels must be heat treated either after brazing or as part of the brazing cycle.

Precipitation-hardening stainless steels can be brazed in a dry hydrogen atmosphere if these alloys do not contain appreciable amounts of aluminum or titanium. Otherwise, they should be brazed in a vacuum or the surfaces of the joint members should be electroplated to permit brazing in a controlled temperature.

Aluminum alloys can usually be brazed. Care must be exercised because melting temperatures are only slightly higher than those of the brazing alloys. Furnace, induction, or dip-brazing equipment should have a control accurate to within 10°F. Torch brazing can be used but considerable operator skill is required.

Most 2000 and 7000-series wrought alloys and many cast alloys cannot be brazed because their melting temperatures are below those of the commercial filler metals.

Aluminum alloys with high manganese content (5086, 5154, and 5456) are difficult to braze because they have poor wetting characteristics. Aluminum alloys for die casting cannot be brazed because they blister when subjected to brazing-cycle heat.

Magnesium-base alloys can be brazed successfully if the precautions given for aluminum are applied.

Joint clearance can be as high as 0.010 in., depending on the amount of overlap in the joint, but 0.002 in. is most desirable.

Copper and its alloys are brazed readily with many filler metals by most conventional brazing processes. Filler metals include copper-phosphorus, copper-zinc, and silver-base alloys.

Copper alloys are usually fluxed when brazing is done in uncontrolled-atmosphere furnaces. However, copper-phosphorus filler metals are self-fluxing when used to braze copper.

Joint clearances for brazing copper range from about 0.001 to 0.005 in., depending on type of joint and flow properties of the filler metals.

Pure copper, particularly oxygen-free grades, is relatively simple to braze. Hydrogen embrittlement may occur if oxygen-bearing copper is brazed in atmospheres that contain even small amounts of hydrogen. For this reason, oxygen-bearing coppers should be brazed rapidly with low-melting BAg or BCuP filler metals.

Silicon, phosphor, and aluminum bronzes should be brazed in a stress-free condition. Special fluxes may be needed with these alloys to prevent formation of oxides that inhibit wetting and flow of the filler metal.

Copper-nickel alloys can be readily brazed, but should be stress relieved before brazing. Copper-phosphorus filler metals are not generally recommended for brazing these base metals, but can be used for 90-10 Cu-Ni.

Copper-zinc alloys can be brazed without difficulty. However, brasses are subject to stress cracking and should be heated gradually.

Beryllium-copper alloy can be brazed with some silver-base filler metals. Brazing should be done during heat treatment with a filler metal whose brazing range fits the heat-treating cycle.

Nickel alloys can be brazed with most filler metals suitable for brazing ferrous metals, if the filler metal has the same oxidation and corrosion-resistant properties as the base metal.

High-nickel alloys are subject to stress-corrosion cracking in the presence of molten filler metals. Parts should be stress relieved before brazing and should be assembled in a stress-free condition.

Superalloys with a cobalt base are the easiest to braze. The process is carried out in a dry hydrogen atmosphere (or in a vacuum) using the nickel-base filler metals or those based on silver, gold, or palladium. Filler metal and brazing cycle must be carefully selected because the properties of cobalt-base alloys (and those of the iron and nickel-base superalloys) can be adversely affected by high brazing temperatures and long brazing cycles.

Iron and nickel-base superalloys are most successfully brazed in a vacuum using nickel-base filler metals or filler metals based on the noble metals.

Dissimilar metal brazing of materials whose physical properties differ markedly can often be minimized by proper selection of the joint design, filler metal, and brazing cycle. Problems associated with metallurgical compatibility of dissimilar metals are more serious, and a thorough understanding of the reactions that occur during brazing is essential. Reactions that occur during the brazing cycle may produce undesirable intermetallic compounds.

Joint clearances should be generous (0.006 to 0.025 in.) to permit flow of the filler metal into the joint and prevent flux entrapment.

Fluxless aluminum brazing has become a commercially accepted method of brazing. Invented by the General Electric Co., the process involves exposing the joint area to the action of magnesium in a nonoxidizing atmosphere. In practice, a vacuum furnace is usually employed, but brazing can also be accomplished in atmospheres of nitrogen or argon.

Special cladding alloys incorporating magnesium are available that eliminate the necessity of adding magnesium in other forms. Certain standard aluminum alloys containing magnesium braze well without modification. Since no flux whatever is used, air and water pollution problems are eliminated. Additionally, water is conserved by completely eliminating rinsing cycles. Licensees of the process have reportedly found the process to be extremely cost effective in mass production.

Joining plastic

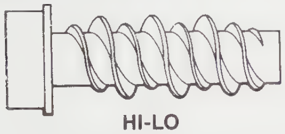
There are different techniques for joining plastic parts. Equipment cost for each method varies considerably, as does the amount of labor involved. Most techniques have limit on the sizes and types of plastic that can be joined.

Mechanical fastening: The simplest way to join plastic parts is to design a fastening element (hinge, latch, detent) into the parts. Only stronger plastics are suitable for this method since the joint must survive the strain of assembly, service load, and possible repeated use. This form of fastening is suitable only for lightly loaded, nonrigid assemblies where precision is not critical.

Mechanical fasteners (screws, rivets, pins, sheet-metal nuts) are the most common joining method. They require a plastic that can withstand the strain of fastener insertion and subsequent high stress around the fastener. Conventional machine screws are rarely used except with very strong plastic.

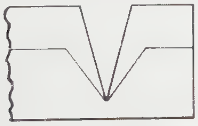
THREAD-FORMING FASTENERS FOR PLASTICS

Dual-height thread design boosts holding power by increasing the amount of plastic captured between threads.



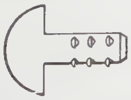
HI-LO

Some specials have thread angles smaller than the 60° common on most standard screws. Included angles of 30 or 45° make sharper threads that can be forced into ductile plastics more readily, creating deeper mating threads and reducing stress. With smaller thread angles, boss size can sometimes be reduced.



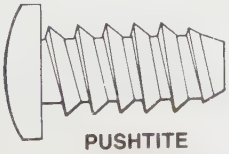
SHARP THREAD

Barbs provide the holding power in this fastener.



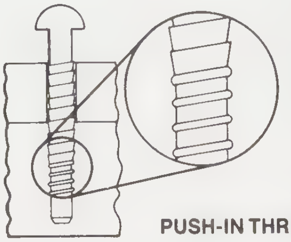
BARBED

Pushtite fastener is pushed into place and can be screwed out.



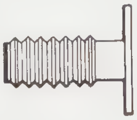
PUSHTITE

For rapid installation on lightly loaded joints, some fasteners have a thread configuration that allows the screws to be pushed into place. This design is typical. Suitable for ductile plastics, this fastener relies on plastics relaxation around the shank to form threads. The thread is helical so that it can be unscrewed, but reuse is limited.



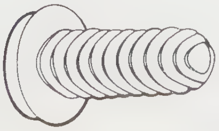
PUSH-IN THREAD

Reverse saw-tooth edges bite into the walls of the plastic.



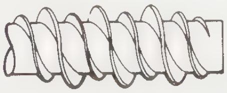
MILFORD

Triangular configuration is another technique for capturing large amounts of plastic. After insertion, the plastic cold flows or relaxes back into the area between lobes. The design also creates a vent along the length of the fastener during insertion, eliminating the "ram" effect. In some ductile plastics, pressure builds up in the hole under the fastener as it is inserted, shattering or cracking the material.

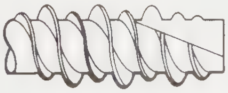


TRILOBE

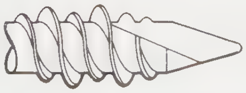
Blunt-tip fasteners are suitable for most commercial plastics. Harder plastics require a fastener with a cutting tip. Hardest plastics require both a piercing and drilling tip, as in these fasteners.



BLUNT

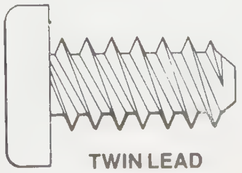


CUTTING



PIERCING

Twin-lead fastener seats in two revolutions.



TWIN LEAD

There are a number of fasteners especially designed for use with plastics. Threaded fasteners work best on thick sections. Thread-forming screws are preferred for softer materials, while thread-cutting screws work best on harder plastics. Push-on locknuts and clips may be better for thinner sections. If a fastener has to be removed a number of times, metal inserts are recommended. They may be molded in place, forced, glued or expanded into molded or drilled holes, or inserted ultrasonically.

Fusion bonding: When plastic parts are too complex or large to be fabricated on available molding equipment, they are sometimes made as subcomponents and welded together by fusion bonding.

To plasticize the part edges, the fixtures press the parts against a heating platen. As the platen melts the part surface, the plastic material is displaced while the fixture maintains part pressure against the platen. This initial fusing produces a smooth surface by removing surface imperfections, warps, or small sinks. Melted material continues to be displaced until "melt stops" on the platen contact the holding fixtures. Material is then no longer displaced and the parts are held against the platen until each part edge is plasticized to a predetermined depth. Melt depth is regulated by contact time, which is usually from 3 to 6 s.

After part edges are plasticized, the fixtures open and the platen is withdrawn. The fixtures then reclose, forcing the parts together until "seal stops" on the fixtures come into contact. The parts are held together under pressure as the melted material cools, bonding them together.

Usually, fusion bonding joins thermoplastics such as polyethylene, polypropylene, and ABS. However, with slight changes, the process can be used to join both filled and unfilled nylon.

To fuse unfilled nylon, a thin, nickel-chrome blade, rather than a platen, is heated to about 1,100°F. The heated blade is brought to within 0.0005 in. of the material in a brief heating cycle. The blade is then removed and the part conventionally fixtured.

Glass-filled nylon can be softened using direct heat, if care is taken to clean the blade or platen with a steel brush between each cycle.

Vibration welding: Vibration welding produces pressure-tight joints in circular, rectangular, or irregularly shaped parts made from almost any thermoplastic material — even in dissimilar materials having a melt-temperature spread as great as 100°F. The process is particularly suited for hollow, container-type components having the weld joint in a single plane.

The parts are frictionally heated by pressing them together and vibrating one of the parts at 120 to 240 Hz, in the plane of the joint.

After 2 to 3 sec, vibration is stopped at the exact required relative position of the two pieces. Pressure is maintained briefly while the softened plastic cools. Joint strength is very near that of the parent material. Cycle time, including manual loading and unloading, ranges between 5 and 8 sec for most parts. The process is adaptable to fully automated systems.

Vibration welding accommodates large parts that are impossible, or at least economically impractical, to weld by other methods. Parts can be rectangular or irregular, as long as the weld joint is in a single plane and a small amount of motion (at least 0.12 in.) in that plane is possible. Components with weld surfaces as long as 20 in. have been successfully joined.

Spin welding: Spin welding, as with inertia welding, joins metal parts. In this process, one element is stationary. The other is attached to a spindle that is brought up to a predetermined speed, then forced against the stationary part. Parts fuse together under the friction-generated heat. One limitation is that the rotating part must be symmetrical.

Solvent bonding: When solvent bonding, plastics are softened by coating them with a solvent, then clamped or pressed together. The plastic molecules mix together, and the parts bond when the solvent evaporates. This process is limited to thermoplastics. Fusion time is a function of the solvent's evaporation rate and may be shortened by heating.

Pure solvents provide the simplest, lowest-cost bond. Doped solvents, which cost more, contain solutions of the plastic being bonded to fill gaps in imperfectly fitting parts. Next in complexity and cost come monomer and polymerizing solvents. These materials contain catalysts and promoters added to doped solvents to produce polymerization at room temperature or a temperature below the softening point of the thermoplastic.

Solvent-bonded parts must be pressed together for 10 to 30 sec before the joined parts can be handled. Pressure is critical, as too much pressure causes parts to distort. A day or more at room temperature or several hours at elevated temperature may be needed to cure the bond.

Solvent bonding can be slow. Solvent is usually applied manually with a dipping operation, a squeegee, or sponge. Then the parts must be clamped together and cured.

Ultrasonic welding: Pulses are transmitted from a generator to the part by a resonant vibrating tool called a horn, causing two plastic materials to vibrate against each other. Vibration heats and fuses the parts together. Recent trends in plastic product development include blending or alloying of different resin families. The need to join these has generated interest in ultrasonic welding. Such dissimilar parts should be designed carefully, and both the resin and equipment suppliers should become involved early to ensure that ultrasonic techniques can produce a suitable bond.

Ultrasonic assembly is generally done at 20 kHz to achieve the vibrational amplitude and power needed to melt thermoplastics. However, higher frequencies that produce less vibration can also join thermoplastics, especially engineering thermoplastics such as reinforced polymers. For some applications, use of 40 kHz means less material degradation. Tooling used for 40-kHz welding is smaller than that used for 20 kHz; therefore, the welds produced at 40 kHz are generally smaller.

Pressure is critical. Too much causes the parts to vibrate as an integral structure with no heating. Too little does not provide enough contact friction or heating.

Ultrasonic welding is fast. Assembly rates of more than 25 parts per minute are possible with a single station. There are no secondary operations, such as coating, inserting, or cleaning. The process requires fairly rigid materials. Dissimilar-material sonic welds can be made, but the melting temperatures of both materials must be quite close, otherwise only the lower-melting material will soften and a bond will not form.

Ultrasonics can also be used to insert metal components into plastic, stake metal and plastic parts together, or spot-weld plastic sections.

Induction welding: Originally, induction welding was done by pressing two pieces of plastic material together around a metal insert. When passed through a 450-kHz magnetic field, the encased metal was heated, and the compression produced a good fusion weld. The metal remained sealed inside the part. The adjacent material was unaffected by the high frequency.

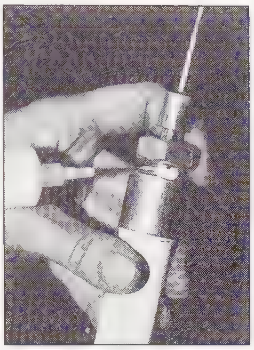
Thermoplastic bonding agents filled with either electromagnetic or ferrite materials may also be used in induction welding. The material, in the form of a preformed ring or strip, or as a hot

Hi - Temp Threadlocking Adhesives

AREMCO Thermo-Lok™ adhesives ...
the threadlocking and sealing solution for fasteners used in harsh environments with severe stress and temperatures to 3200° F

Thermo-Lok™ Applications

- Lock and seal metal fasteners up to 3200°.
- Lock fasteners into refractory (ceramic) structures.
- Lock fasteners into high temperature flange areas.
- Lock sensors into automotive and aircraft engine compartments.
- Repair high temperature manifold and gasket surfaces.



Order Thermo-Lok™ 675 KIT today, including three different materials for $75 or **ASK FOR DATA.**

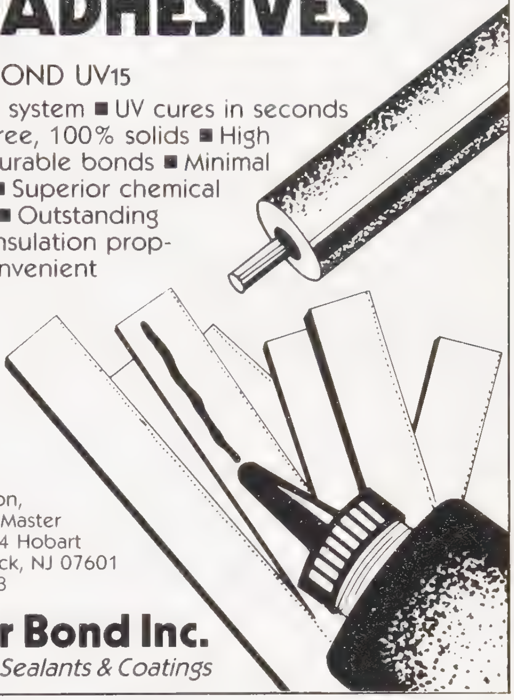
For more information:
Tel: 914/762-0685
Fax: 914/762-1663

AREMCO PRODUCTS, INC.
P.O. Box 429 • Ossining, NY 10562-0429

Circle 299

TRIPLE PRODUCTION
UV CURE ADHESIVES

MASTER BOND UV15
■ One part system ■ UV cures in seconds ■ Solvent free, 100% solids ■ High strength, durable bonds ■ Minimal shrinkage ■ Superior chemical resistance ■ Outstanding electrical insulation properties ■ Convenient packaging



For information,
call or write: Master
Bond Inc., 154 Hobart
St., Hackensack, NJ 07601
201-343-8983

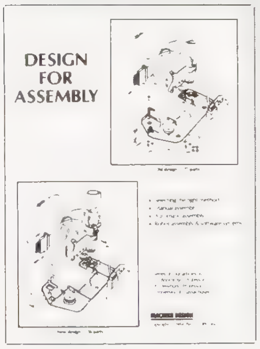
Master Bond Inc.
Adhesives, Sealants & Coatings

Circle 300

HOW TO DESIGN FOR LEAST-COST ASSEMBLY AND . . .

cut manufacturing costs up to 40% . . . improve assembly, productivity up to 200% . . . in this series of four articles, **"Design for Assembly,"** from MACHINE DESIGN. Contents:

Selecting the right assembly method,
Eliminating many time-consuming manual assembly steps,
Designing for automatic assembly,
Designing for robotic assembly,
Software system aids to analysis.
1984 . . . 22 pages . . . softbound.



A MUST REFERENCE FOR YOU AND EACH MEMBER OF YOUR DESIGN STAFF!

One copy	$9.50
2-9 copies	$8.74 each
10-24 copies	$7.98 each
25-49 copies	$7.12 each
50-99 copies	$6.36 each
100 or more copies	$5.70 each

Order your copies now!
Call toll-free 800-321-7003 (in Ohio call 216/696-7000) or send the coupon below to:

Penton Education Division
1100 Superior Avenue
Cleveland, Ohio 44114

Please send me _____ copies of **"Design for Assembly"** at $_____ per copy. I understand that I may review the articles and, if not satisfied, I may return them for full refund or credit.

My payment is enclosed for postage-free shipment in the U.S. and Canada.
Orders less than $15.00 must be prepaid.
☐ Bill my company and include postage and handling charges. My purchase order is enclosed.
Charge my ☐ Visa ☐ MasterCard ☐ American Express card.

Acct. No. ____________________ Exp. date ______
($15.00 minimum)
Name ____________________ Title ____________
Company ____________________
Address ____________________
City ____________ State ______ Zip ______
Signature ____________________

Penton Education Division * 1100 Superior Avenue
Cleveland, Ohio 44114

melt, for instance, is inserted between the mating parts before induction heating. If metallic particles are used, the alternating magnetic field induces current flow within the particles, generating heat. When ferrite is used, no current is produced. Instead, heat is produced by molecular friction as the particles try to retain their magnetic charge when the fields are reversed.

To eliminate the need to add metal to the joint, metal powder can be added to the original plastic molding, but a much higher frequency is needed (3 to 5 MHz) to produce an effective weld.

Induction welding is a high-cost technique and is suitable for difficult-to-weld plastics such as polypropylene, and for shapes that cannot be fitted into an ultrasonic welding machine. The process is best suited for bonding most polypropylene, polyethylene, styrene, ABS, polyester and nylon in high-volume, highly automated joining operations.

Heat-resistant polypropylenes that cannot be joined with adhesives or with other welding techniques may be successfully joined using induction welding. Bonding agents heated inductively reach temperatures of 300°F in 0.1 sec to fuse with the heat-resistant substances.

Dielectric welding: Dielectric welding is used on films and thin sheets up to about 60 mil, primarily in packaging processes. The technique utilizes the breakdown of plastic under high voltages and frequencies (13 to 120 MHz) to produce dielectric heating and fuse the plastic. Welding speed is a function of dielectric-loss factor, material thickness, and the area subjected to the impressed voltage. Dielectric welding is ideal for PVC materials.

Joining composites

Mechanical fasteners, adhesives, or both are used to join composites. The joining technique used on a particular composite depends on the application and the material composition. For instance, composites used in aircraft are usually joined by a combination of mechanical fasteners and adhesives, whereas those used in automobiles are often joined only with adhesives.

Theoretically, all composites could be adhesively bonded. However, many

CHARACTERISTICS OF ULTRASONIC AND VIBRATION JOINING

Thermoplastic materials, because they melt easily and retain their original properties when cooled, may be joined using vibration or ultrasonic welding. Thermosets are not good candidates for these bonding techniques, as they often degrade when heated.

However, certain thermoplastics have properties that are more conductive to bonding ultrasonically. For instance, amorphous resins, which have a random molecular arrangement and a broad melting and softening range, are better candidates for ultrasonic bonding than crystalline resins, which have an orderly molecular arrangement and specific melting temperatures.

Energy transmission characteristics of resins affect the near-field and far-field weldability of materials. Near-field and far-field welding refer to the positions of the joint in relation to the ultrasonic horn. A joint within ½ in. of horn contact is near-field welded, while one further away is far-field welded. Therefore, the further the joint from horn contact, the more significant the energy transfer properties of the resin.

Ultrasonic versus vibration joining

	Ultrasonic welding					
	Ease of welding		Swaging and staking	Inserting	Spot welding	Vibration welding
Material	**Near-field**	**Far-field**				
Amorphous resins						
ABS	E	G	E	E	E	E
ABS/Polycarbonate alloy (Cycoloy 800)	E-G	G	G	E-G	G	E
Acrylic	G	G-F	F	G	G	E
Acrylic multipolymer (XT-polymer)	G	F	G	G	G	E
Butadiene-styrene (K-Resin)	G	F	G	G	G	G
Cellulosics — CA,CAB, CAP	F-P	P	G	E	F-P	E
Phenylene-oxide base resins (Noryl)	G	G	G-E	E	G	E-F
Polyamide-imide (Torlon)	G	F				G
Polycarbonate	G	G	G-F	G	G	E
Polystyrene (general purpose)	E	E	F	G-E	F	E
Rubber modified (high-impact)	G	G-F	E	E	E	E
Polysulfone	G	F	G-F	G	F	E
PVC (rigid)	F-P	P	G	E	G-F	G
SAN-NAS-ASA	E	E	F	G	G-F	E
Crystalline resins						
Acetal	G	F	G-F	G	F	E
Fluoropolymers	P					F
Nylon	G	F	G-F	G	F	E
Polyester (thermoplastic)	G	F	F	G	F	E
Polyethylene	F-P	P	G-F	G	G	G-F
Polymethylpentene (TPX)	F	F-P	G-F	E	G	E
Polyphenylene sulfide	G	F	P	G	F	G
Polypropylene	F	P	E	G	E	E

E = Excellent, G = Good, F = Fair, P = Poor. Ease of welding is a function of joint design, energy requirements, amplitude, and fixturing.

manufacturers avoid adhesive bonds where joints undergo large amounts of stress; thus, fasteners are still specified for many joints. Also, some structures and components are so large that they preclude the use of the special lay-up tooling and curing equipment needed for most adhesive applications, making fasteners cost-effective for such cases.

Mechanical fasteners: Rivets, pins, two-piece bolts, and blind fasteners made of titanium, stainless steel, and aluminum are all used for composites. Several factors should be considered when specifying fasteners for composite materials:

- Differential expansion of the fastener in the composite.
- The effect of drilling on the structural integrity of the material, as well as delamination caused by fasteners under load.
- Water intrusion between the fastener and composite.
- Electrical continuity of the composite and arcing between fasteners.
- Possible galvanic corrosion at the composite joint.
- Weight of the fastening system.
- Fuel tightness of the fastening system, where applicable.

Aluminum and stainless-steel fasteners expand and contract when exposed to temperature extremes, as in aircraft applications. In carbon-fiber composites, contraction and expansion of such fasteners can cause changes in clamping load. Potential clamping changes should be determined before the fastening system is chosen so joint design can be modified accordingly.

Drilling and machining can damage composites. The number of defects, such as delamination, resin erosion, and fiber breakout allowed in any structure depends on the application. For instance, because joint failure in carbon-fiber composites is caused primarily by localized bearing stress rather than overall stress, delamination is a much more serious defect than fiber breakout in a carbon-fiber composite application.

Drilling techniques and the tools selected are determined by the resin, the fiber or fiber combinations in the resin, the way the fibers are configured, and the composite/metal composition of the structure.

Fasteners for composites should have large heads to distribute loads over a larger surface area. In this way, crushing of the composite is reduced. Fasteners should also fit closely to reduce the chances of fretting in the clearance hole. Interference fits may cause delamination of the composite. Special sleeved fasteners can limit the chances of damage in the clearance hole and still provide an interference fit. Fasteners can also be bonded in place with adhesives to reduce fretting.

When carbon-fiber composites are cut, fibers are exposed. These fibers can absorb water, which both weakens the material and adds weight to the structure. Sealants can prevent moisture absorption in the clearance hole, but this both complicates the process and adds cost. It also defeats any effort made to maintain electrical continuity between the composite fibers and the fasteners. Sleeved fasteners can provide fits that reduce water absorption, as well as provide fuel tightness.

Additionally, carbon-fiber composites may corrode galvanically if aluminum fasteners are used, due to the chemical reaction of the aluminum with the carbon fibers. Coating the fasteners guards against corrosion but adds cost and time to assembly. Aluminum fasteners are often replaced by more expensive titanium and stainless steel when carbon-fiber composites are used.

Adhesive bonding: Composite bonds with adhesives generally are not weakened by drilling or other machining. Adhesives have been used to assemble composite components, such as rotor blades and airplane wings, and are sometimes used to join structural components. Bond reliability of adhesive joints is sometimes questioned, however, and fasteners are still specified as reinforcements for many composite applications.

Three adhesives are often used to bond composites: epoxies, acrylics, and urethanes. Epoxies are especially reliable when used with epoxy-based composites because they have similar flow characteristics.

Epoxies are suitable for joining fiber-reinforced plastic (FRP) in relatively high-volume applications where automatic dispensing equipment is used. Adhesion and environmental stability of epoxies are excellent, so mixed epoxy has a long pot life.

Polyurethane adhesives are also used to bond composite materials. They are suitable for joining flexible composites because polyurethanes make flexible bonds. They also cure quickly at room temperature. However, urethane adhesives are sensitive to moisture and require complex dispensing equipment.

Acrylics are used to bond composites but are somewhat rigid. Acrylics also cure quickly at room temperature; bond unprepared substrates; can be mixed, metered, and dispensed a variety of ways; and have a long pot life. However, acrylics smell bad, are flammable, have poor impact resistance at low temperatures, and may shrink.

Careful surface preparation of adherend surfaces is essential to making a quality adhesive bond, but preparation varies depending on the adherend and adhesive used. Recommended preparation of many composite adherends consists of a solvent wipe to remove loose surface dirt and oil, and an abrading operation. Abrasion should be done carefully to avoid damaging composite surface fibers.

In some cases, primer is required to coat the composite before applying the adhesive. When bonding composites to metals, the metal substrate can be prepared by blasting with sand, grit, or metal oxides; abrading with a wire brush; and machining or scoring with cutting tools. Metal surfaces can also be prepared chemically. To protect freshly prepared metal surfaces from corrosion and contamination, adhesive should be applied as soon as possible.

Metals and ceramics

Many applications require joining metals to ceramics. These include sealing electrodes to glass enclosures for vacuum tubes and light bulbs. Such joints need to provide continuous chemical contact across the interface through chemical bonding to the mating materials. Several techniques are available to provide metal-to-ceramic bonds.

Solder glass: Seals between metals and glass can be made through collapsing a low-temperature glass around the glass/metal interface. As the intermediary glass is acting as a solder it is referred to as "solder glass."

Metallic bonding systems: There are four techniques for metallizing ceramics that rely on strong chemical bonding to create an adherent joint. They are:

Refractory metallizations: These entail sintering molybdenum or tungsten powders to glassy-phase-containing oxides. Often, bond-enhancing additives are used. Here, the refractory metal powders simultaneously sinter both together and to the ceramic. The glassy phase in the ceramic will migrate into the metallic layer filling in the interstices within the metal powder layer, thus chemically and mechanically interlocking with the metallic layer. Subsequent nickel plating of this layer achieves a solderable or brazeable surface. This technique has been used to produce seals and circuitry for alumina, beryllia, and mullite.

Active metal brazing: Adding titanium, zirconium, or hafnium to standard silver-based braze alloys forms an activated alloy. By firing such an alloy onto ceramic surfaces at 800 to 1,000°C in vacuum or argon, the braze will wet directly onto the ceramic through migration of the active metal toward the ceramic/metal interface accompanied by strong bonding potential of the active metal. This technique has been used for electronic sealing as well as for joining structural ceramics such as silicon nitride turbocharger blades to corresponding metal parts.

Direct chemical bonding: Tin directly bonds to various ceramics and metals if mixed with particular transition metals and fired to 580 to 1,000°C in carbon monoxide. Applications include general ceramic-to-metal soldering as well as very thermodynamically stable braze joints on standard alumina compositions, zirconia, and graphite. The bonding theory suggests that a tin transition-metal phase forms within the tin matrix and then undergoes oxy-carbide formation on the surface. This oxy-carbide layer would then diffuse into the substrate to form a transition zone.

Direct bond copper: Copper's melting point is slightly lowered through eutectic phase formation with a small amount of oxygen. The surface of a copper shim is oxidized. It is fired in an inert or slightly oxidizing atmosphere between the eutectic temperature and the melting point of pure copper. This copper oxide then will melt and diffuse into most oxide substrates. On alumina, an intermediary reaction zone of copper aluminate forms.

Other metallization techniques include metal-filled frits (glassy phases) which, when fired onto the ceramic, establish bonding through glassy phase interaction. The metallic phase migrates toward the top of the coating and can be joined metallurgically. In treating the superconducting oxide $YBa_2Cu_3O_{7-x}$, silver can be fired on the surface in a pure oxygen environment. Silver oxide forms which diffuses into the substrate and the rest reduces to pure silver upon cooling.

Injected metal

The injected-metal assembly (IMA) process provides permanent, reliable assemblies by injecting a small amount of molten zinc or lead alloy into and around components being joined. The molten metal cools and solidifies, accompanied by minute shrinkage that locks the injected metal onto the components. IMA can assemble small parts made of materials including ceramics, glass, plastics, pressed paper, elastomers, fibers, and metals. The technique can be used in place of staking, brazing, soldering, electron-beam welding, riveting, press or shrink fitting, and crimping.

During assembly, components are positioned and held by a custom-designed tool carried in the operating head. Molten metal is injected into the tool cavity containing the mating surfaces of the parts. Grooves, knurls, undercuts, splines, holes, and other features are enveloped by the metal flowing into the cavity. The metal solidifies and shrinks to form a permanent bond. Injection and solidification take about 0.5 to 1.0 sec, after which the assembly is ejected.

Custom-made tooling, essential to the IMA process, serves several functions. It holds the parts in the exact relationship required for final assembly and also rejects oversize components. While the tool helps check tolerances on outer diameters, mating tolerances may be looser, as the injected metal will fill any gaps.

Tool inserts permit variations of a basic assembly, and changing tools can adapt IMA systems for a variety of assemblies. In addition, because the process is derived from die casting, tool cavities can be designed to cast components integrally with the hub. Building the mold into the tool allows users to form parts such as pinions, cams, hubs, sleeves, and rivets during one machine cycle. With appropriate tooling, several components can be joined to a shaft at once.

As assemblies leave the system, they contain no flash, runners, or sprues, and require no secondary finishing operations. Applications which benefit from the use of IMA include those where a component can be replaced by a shape formed as part of the joint, or where components would have otherwise required tight tolerances to ensure concentricity.

Required strength normally dictates the metal used. Lead alloy is common in lightly loaded applications. However, most applications use a zinc alloy known as Zamak 3. While molten, this alloy easily can be injected into thin cross sections and intricate shapes while maintaining 41,000-psi tensile strength upon solidification. Higher strength requirements are met by Zamak 5, which provides 47,600 psi strength.

IMA systems have size limitations. Typical size for a completed assembly is up to 6 in. in the largest dimension. When several parts are assembled, the number of holding features required may limit the size. On the other hand, components can be assembled to the ends of shafts and cables of unlimited length. Present IMA equipment can inject only up to 1 cu. in. of molten metal. This limits the size of the injected hub.

The permanance of IMA may be an advantage or disadvantage, depending on the application. Assemblies may be difficult to take apart without damaging the components.

Parts may be fed into the assembly tool manually or automatically, but injection and unloading are automatic. Systems can work as stand-alone units or as part of an assembly line. Production rates range from a few hundred to over 1,000 assemblies/hr.

Clinching

Clinching is a combination of drawing and forming that locks together layers of sheet metal. Multiple layers can be joined, though clinching is most commonly used for only two layers. The method can replace spot welding, riveting, metal screws, brazing, and staking or crimping. In clinching, a punch drives the two layers of metal into a die that produces an impression. Additional force spreads the upper layer of material into the lower layer, so it cannot be pulled out.

Two basic clinching methods are used. The older one, often called a clinched or lanced lock, shears the metal, forcing the top layer through slits in the bottom layer. This method is primarily used for metals with less ductility, such as hard aluminum or stainless steel, or where there is a considerable thickness or ductility difference between the sheets being joined.

The second method, called a button or round clinch, produces no hole but simply deforms both layers so that the bottom layer locks around the top, like a circular dovetail joint. This joint is often preferred because of its neater appearance and leak resistance.

Both processes require use of ductile sheet metals, such as steel, aluminum, or brass in light gages. Many plastics are difficult to clinch because they tend to resume their original shape after being clinched. Materials that cannot be properly clinched often can be locked between two layers of metal, however.

Factors limiting clinching are mainly joint thickness and the distance of the joint from the edge of the material. Both these limits vary with the tooling vendor chosen. Joint thickness is generally limited to a total of 0.25 to 0.30 in., but minimum joint-to-edge distances may range from 0.06 to 0.25 in. ■

Joint design

Reliable joint designs must consider method, materials, and geometry.

Each joining technique has particular design requirements, while certain joint requirements may suggest a particular joining technique. Bolting is a common fastening method, for example, but welding may reduce the weight of an assembly.

Naturally, joints designed for the two techniques would differ greatly. However, all joint designs must consider characteristics such as load conditions, assembly efficiency, operating environment, overhaul and maintenance, and the materials used.

Stable bolted joints

Reliable joints require:

- A firm, strong connection.
- Materials that are stable in the environment.
- Stable geometry.
- Appropriate stresses in the parts, including a correct clamping force.

Joint strength: Bolted joints should prevent slip, separation, vibration, misalignment, and wear of parts. Joints and bolts must deflect elastically but must be rigid enough to provide structural integrity. Rigid joints result from specifying enough bolts of adequate diameters, strong enough bolt and joint materials, sturdy joint members, and correct installation procedures.

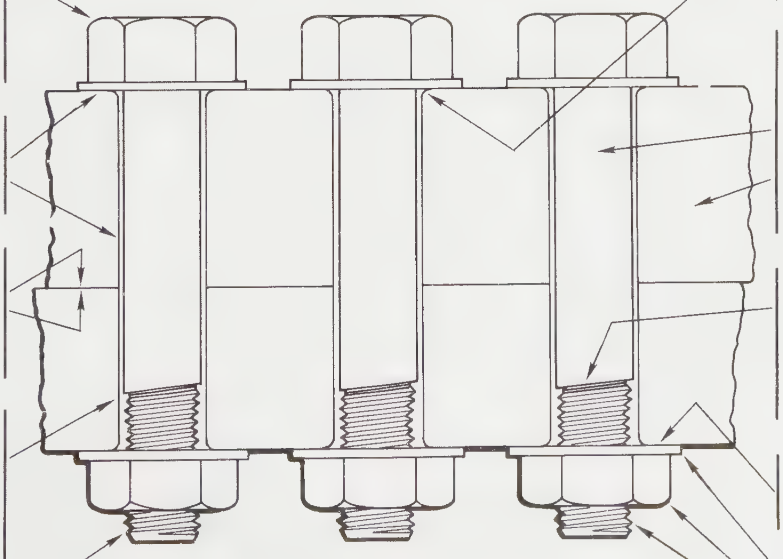
Well-designed joints provide strength and integrity without being excessively large or heavy, or requiring assemblers to use bulky tools. The specific geometry and materials for a joint depend on the application, but general guidelines can be given.

For instance, bolt size should be specified so that tensile stress is no greater than 60% of bolt yield strength, though this percentage may vary depending on the application. For example, concern about stress-corrosion cracking might dictate 20% preloads, while some slip-critical joints may be loaded beyond 100% of the bolt yield strength.

Stronger bolt materials can often decrease the size and number of bolts required, cut assembly costs, and permit use of smaller joint members. However, stronger is not always better. Increased strength is usually accompanied by an increase in hardness and resulting loss of ductility.

In relative terms, bolts should be flexible and joint members stiff. A favorable stiffness ratio can be produced by using bolts with the largest possible length-to-diameter ratio (L/D), and an extreme L/D ratio, such as 8:1, may

THE RELIABLE BOLTED JOINT



Bolt heads and nuts are readily accessible for accurate preload control during tightening. Use the most accurate tightening tools and procedures that costs permit.

Bolt hole axis is perpendicular to joint-member surfaces to reduce stress concentrations.

Joint surfaces are flat and parallel to each other, reducing stress concentrations, especially bending stress.

Hole is large enough to avoid cramping or interference during assembly, but small enough to minimize slip distances and to maximize head, washer, and nut-to-joint bearing surfaces.

Bolt extends two full threads past the outer end of the nut.

Bolt distribution is uniform around the line of action of external tensile loads on the joint. Loads are not offset. Likewise, the line of action of shear loads should pass through the centroid of the bolt pattern.

Bolt holes are located within two diameters of one another if gaskets are used. If this is impossible, change joint thickness, bolt diameters, or both to provide uniform contact-stress distribution between joint members.

Bolt hole is chamfered to eliminate burrs and provide clearance for bolt head-to-body fillet. This eliminates potential stress concentrations and postassembly relaxation.

Stiff joint and flexible bolts provide the maximum practical joint-to-bolt stiffness ratio, minimizing the effects of external loads and temperature change on bolt stresses.

Thread runout does not coincide with the joint interface to avoid overlapping stress concentration effects.

Hard washers distribute contact stresses uniformly.

Bolts, nuts, washers, and joint members are of similar or identical materials to minimize differential thermal expansion and galvanic corrosion.

make a bolt immune to such things as vibration loosening.

Bolt and joint materials should have similar coefficients of thermal expansion, so the bolts will not work against the joint when temperature changes. If identical coefficients are impossible, closer attention should be paid to a favorable L/D ratio, so bolt flexibility can offset differences in thermal expansion.

Stable materials: Strength is important when choosing a bolt material, but it is not the only material factor to consider. Often, bolts should also:

- Resist corrosion.
- Resist stress-corrosion cracking.
- Resist fatigue.
- Maintain stiffness at high temperatures regardless of a loss in elastic modulus.
- Not lose tension because of stress relaxation or creep.

Common bolting materials may not be suited to extreme conditions. For example, a fairly exotic bolting alloy such as MP35N may be needed if a combination of unusual properties — such as high strength and stress-corrosion resistance — is required.

Stable geometry: Several refinements of bolt and joint geometry can improve clamp stability. Many of these refinements reduce stress concentrations, which can significantly shorten bolt fatigue life.

For example, if the joint will be loaded in shear, thread runout on the bolts should not coincide with the shear plane between joint members. This situation combines the normal stress concentrations at thread runout with additional concentrations located at the shear plane. Fillets between the head and body of the bolt can also reduce stress concentrations, and making fillet cross sections elliptical may offer further improvements.

Stress concentrations may also be reduced by rounding the roots of thread teeth, tapering thread runout instead of ending the thread abruptly, and using flanged-head instead of hex-head bolts. Rolling the bolt threads after heat treatment, instead of before, and shot peening bolt surfaces can also improve stability under fatigue or stress-corrosion conditions.

Clamping force: The main purpose of the bolt is to clamp parts together with enough force to prevent loosening in service. Clamping force depends on a combination of stress introduced at assembly and the service loads imposed on the joint. Selecting the right clamping force and producing it at assembly are critical.

Too high a clamping force causes excessive stress in bolts, joint members, and gaskets. High stress can damage parts, open leak paths, and encourage stress-corrosion cracking or fatigue failure. Also, overstressed gaskets can lose their ability to respond to a decrease in load, opening a leak path when the system is pressurized.

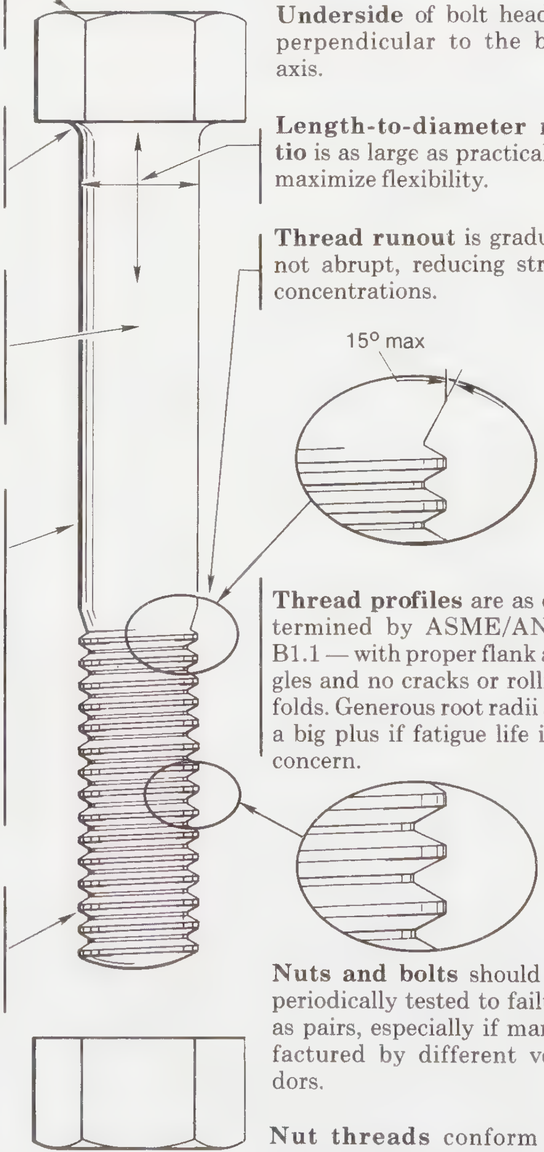
Insufficient clamping force can result in the same lack of joint strength or rigidity as using too few or too small bolts. Improperly tightened bolts may loosen under vibration, thermal cycles, or other in-service conditions. Such joints can also slip, putting excessive loads on bearings or causing wear between parts. Loose gasketed joints can leak. Insufficient tension can also lead to early fatigue failure under cyclic loads.

Bolted joint uncertainties

Designing for stability is especially important because many variables that affect joint behavior cannot be directly controlled. Some of the major causes of uncertainty include:

Assembly: Clamping force is estab-

THE RELIABLE BOLT



Bolt head is marked, showing the strength grade of the material, and it should also display a manufacturer's identification mark.

Fillet blends head to bolt body. An elliptical profile has greater fatigue resistance than a circular profile.

Hardness of common materials such as J429 Grade 5 or ASTM A325 should be no greater than HRC 32 to minimize potential stress cracking.

Coating is uniform to resist corrosion and to reduce scatter in the torque/tension relationship. Solid-film molybdenum disulfide or PTFE coatings are common. Some suppliers recommend mechanically applied mixtures of zinc and aluminum. Electroplating requires caution; improper baking following plating encourages hydrogen embrittlement.

Threads are rolled, not cut. Threads rolled after heat treatment, rather than before, improve fatigue resistance.

Nut proof load should equal or exceed the minimum tensile strength of the bolt.

Strength at operating temperatures is adequate, as is resistance to service conditions such as fatigue and corrosion.

Underside of bolt head is perpendicular to the bolt axis.

Length-to-diameter ratio is as large as practical to maximize flexibility.

Thread runout is gradual, not abrupt, reducing stress concentrations.

Thread profiles are as determined by ASME/ANSI B1.1 — with proper flank angles and no cracks or rolling folds. Generous root radii are a big plus if fatigue life is a concern.

Nuts and bolts should be periodically tested to failure as pairs, especially if manufactured by different vendors.

Nut threads conform to ASME/ANSI B1.1 and are free of cracks. Thread axis is perpendicular to nut face.

lished by assembly operations, and it is subject to a great deal of variation. About 75 factors affect the tension created in a single bolt when a torque is applied, and more than 250 variables come into play when a group of bolts is tightened. Many of these variables can be identified, but they rarely can be characterized for a production lot.

Service loads: Through testing and experience, some industries can quantify the loads on their joints with a fair degree of certainty. However, while machinery and consumer-product manufacturers can predict the loads their products should be exposed to, they cannot quantify conditions the product might experience through customer ignorance or abuse. Even when products are used properly, service conditions may vary.

Load distribution: Another area of uncertainty is the way parts of a bolted joint share external loads. Here, the stiffness ratio between bolts and joint members is key. Relatively flexible bolts will experience a smaller change in stress for a given change in tensile load on the system, which can enhance bolt fatigue life.

Bolt stiffness may be uncertain because it depends on effective bolt length, the length of the bolt that acts as a spring. There are several ways to estimate effective length. One rule of thumb assumes that one-half the nut or hole threads are loaded. However, the accuracy of this rule varies with joint geometries and conditions.

The greater the length-to-diameter ratio of the bolt, the less effect thread engagement has on effective length. However, on short bolts, thread engagement can significantly affect effective length and stiffness estimates.

Thermal effects: The response of bolts and joints, especially gasketed ones, to temperature change is also uncertain. It is known that high temperature affects the strength and modulus of bolting materials. However, these properties may vary from lot to lot and manufacturer to manufacturer, so quantitative evaluations of temperature effects are difficult.

Data about expansion coefficients of bolting materials and stiffness ratios are also limited. Such data are needed to estimate the change in clamping force created by expansion or contraction of bolts and joint members.

Even less information is available about other material properties. Temperature influences failure modes such as stress-corrosion cracking, hydrogen embrittlement, fatigue, and corrosion, making exact predictions rarely possible.

Also, gasketed joints often start leaking after a thermal change or series of thermal cycles, but the reasons why are unknown. Factors may include creep of gaskets and metal parts, degradation and change in gasket-material properties, and loss of clamping force on the gasket caused by cycles of thermal expansion and contraction. Efforts are being made to model and predict elevated-temperature behavior, but results will not be available for several years.

Designing for reliability

Though the uncertainties involved make exact predictions impossible, designers can solve many problems based on past experience, trial and error, tests, and the like.

Much experience is accumulated in design rules or recommendations, such as the rules for bolted joint design in the ASME Boiler and Pressure Vessel Code. Many industries and companies have similar guidelines.

Where such rules do not apply, designers must create their own, building on experience with the product as it is manufactured and used. It helps to document decisions and discoveries. If early assemblies fail, careful records of assembly practices can produce better results. Likewise, information about failures and customer problems can evaluate a design more accurately than simple experiments or tests.

The designer should also be intimately involved with the assembly process, at least on critical joints. If part configuration makes it difficult to obtain proper bolt preload, the design is inadequate.

For critical joints, ultrasonic equipment may enable designers to overlook many assembly variables. For example, if bolt tension can be measured directly, variables affecting tension can be ignored. Ultrasonic equipment can also monitor joint response to external loads, load cycles, changes in assembly procedure, and such. This can help designers become familiar with joint characteristics more quickly.

Traditionally, the main weapon against uncertainty is overdesign. More and larger bolts are typically used, with the goal that the joint will be sufficiently clamped even if the bolts are not all tightened correctly, service loads exceed estimates, stiffness ratios were overestimated, or thermal effects were underestimated. In many cases, overdesign is the only option.

Reliability is expensive. Costs are related to the amount of experiment and analysis performed at the design stage; trade-offs between performance and overdesign; the cost of tools and procedures used at assembly; and the cost of bolts and joint members. In critical situations, costs may be boosted by finite-element analyses, optimized designs, exotic materials, and ultrasonic control of bolt stress.

In most cases, testing requirements are much less extensive. However, although the uncertainties involved mean that the cost of improving reliability is not always recouped, in most cases the money is well spent.

Welded joints

Welding is often a cost-effective way to fabricate. It does not require overlapping materials, so it eliminates excess weight caused by other fastening means. Fasteners do not have to be bought and kept in inventory. Welding also can reduce costs associated with extra elements, such as angles fastened between parts.

Moreover, welded joints distribute operating stresses evenly. However, design of a welded joint significantly affects the welding processes that are used. Many design options permit excellent welding performance. Nevertheless, designers who are unaware of the range of technology and methods available may fail to realize welding's potential.

Just as joint design affects welding processes, so must the process be considered when designing a joint. Designs must account for the heating produced by welding, and accessibility for the various processes involved is important as well.

Design considerations

Several structural design considerations should be taken into account for economical and efficient welding. Many of these apply to other joining methods, and all apply to both subassemblies and the complete structure.

Recognize and analyze the design problem: Designs must perform well under expected and worst-case conditions. The designer should consider this before sitting down at the drawing board or CAD terminal.

Considerations include: Is it more economical to build an irregular shape from welded pieces or to cut it from a plate, with the accompanying waste? Can bending replace a welded joint? Are preformed sections available? How, when, and how much should the structure be welded? Can weight be taken out of the structure cost-effectively by using welded joints? Will fewer parts offer the same or better performance?

Determine load conditions: Structures will be subject to tension, compression, torsion, and bending. These loads must be calculated under service conditions. Locations of critical loads must be determined, and the structure designed to handle the loads efficiently. Careful designers will locate joints away from high-stress areas when possible.

Consider producibility: The most elegant design is useless if it cannot be made efficiently. Welders cannot always fabricate what designers think up. Designers should spend time in the fabrication shop and consult foremen or manufacturing engineers during the design process to become familiar with the challenges of translating drawings into products.

Optimize layout: When drawing the preliminary design, engineers should plan layout to reduce waste when the pieces are cut from plate. Preformed beams, channels, and tubes also may reduce total costs without sacrificing quality.

Anticipate plate preparation: Many designers assume that metals are homogeneous, but real-world metal does not have equal properties in all directions. Therefore, the type of plates used should be considered.

Many properties of rolled plates are directional, with the most desirable properties in the direction of rolling. Strength and ductility often are low through the thickness because nonmetallic impurities in many plates weaken them in that direction. Thus, designers should avoid loading rolled plates through their thickness.

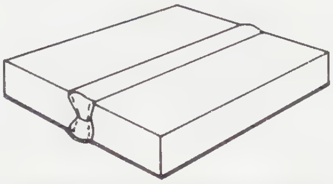
One way to get around through-thickness problems is called buttering. Joint surfaces are gouged or ground out and refilled with weld metal, so welds are made against weld metal instead of base metal. The properties of weld metal do not vary so much with direction because the weld metal was never rolled.

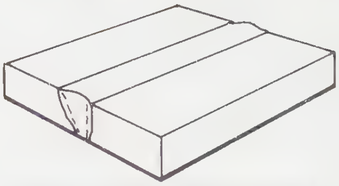
Designers must also plan for residual stresses in joints from weld shrinkage. These stresses may cause lamellar tearing in the base metal, especially in thick plate weldments.

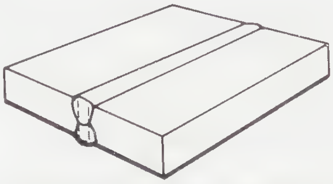
In addition to inherent metal properties, designers must consider how those plates must be prepared for welding. Parts must be thoroughly cleaned before they are welded, and some joints require machined bevels or grooves.

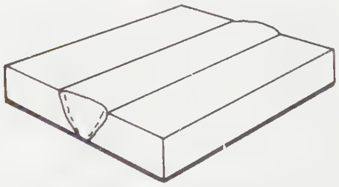
Consider using standard sections and forms: Preformed sections and forms should be used in designs whenever possible. Specifying stan-

TYPES OF WELDED JOINTS


DOUBLE BEVEL- GROOVE WELD

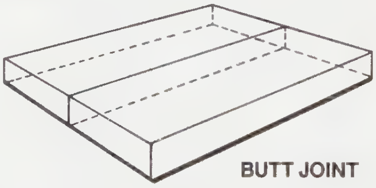

SINGLE BEVEL- GROOVE WELD


DOUBLE SQUARE- GROOVE WELD


SINGLE V-GROOVE WELD

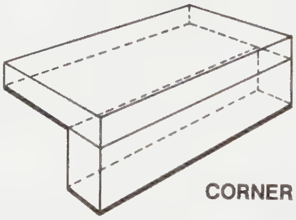
The American Welding Society classifies welded joints into five basic types: butt joints, corner joints, T-joints, lap joints, and edge joints.

The basic welds used in making these joints are more numerous. They are distinguished by the type of grooves used. Single welds, or welds from one side, include square groove, bevel groove, V-groove (with or without backing), J-groove, U-groove, flare bevel groove, and flare V-groove. Double welds, or welds from both sides of the work, include double square-groove, bevel-groove, V-groove, J-groove, U-groove, flare bevel-groove, and flare V-groove welds.


BUTT JOINT

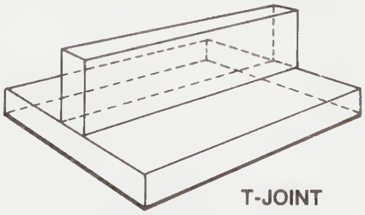
APPLICABLE WELDS

- Square groove
- V-groove
- Bevel groove
- U-groove
- J-groove
- Flare V-groove
- Flare bevel-groove
- Edge flange
- Braze


CORNER JOINT

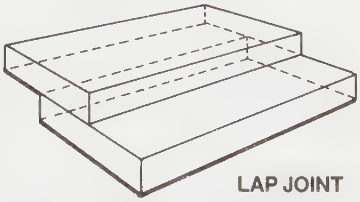
APPLICABLE WELDS

- Fillet
- Square groove
- V-groove
- Bevel groove
- U-groove
- J-groove
- Flare V-groove
- Flare bevel-groove
- Edge flange
- Corner flange
- Spot
- Projection
- Seam
- Braze


T-JOINT

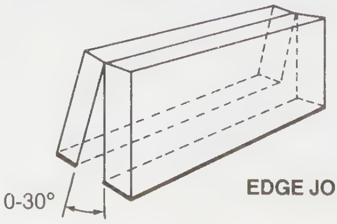
APPLICABLE WELDS

- Fillet
- Plug
- Slot
- Square groove
- Bevel groove
- J-groove
- Flare bevel-groove
- Spot
- Projection
- Seam
- Braze


LAP JOINT

APPLICABLE WELDS

- Fillet
- Plug
- Slot
- Bevel groove
- J-groove
- Flare bevel-groove
- Spot
- Projection
- Seam
- Braze



EDGE JOINT

APPLICABLE WELDS

- Square groove
- Bevel groove
- V-groove
- U-groove
- J-groove
- Edge flange
- Corner flange
- Seam
- Edge

dard sections for welding is usually cheaper than welding many individual parts. In particular, specifying bent components is preferable to making welded corners.

Select weld-joint design: There are five basic types of joints: butt joints, corner joints, T-joints, lap joints, and edge joints. In addition, the American Welding Society recognizes about 80 different types of welding and joining processes. Each process has its own characteristics and capabilities, so joint design must be suitable for the desired welding process. In addition, the joint design will affect access to the weld.

Restrain size and number of welds: Welds should match, not exceed, the strength of the base metal for full joint efficiency. Overwelding is unnecessary, increases costs, and reduces strength.

Welding sometimes induces distortions and residual stresses in structures. It is best to specify the minimum amount of welding needed. To check for overwelding, determine joint stresses vs. stress in the adjoining

JOINT DESIGN CONSIDERATIONS

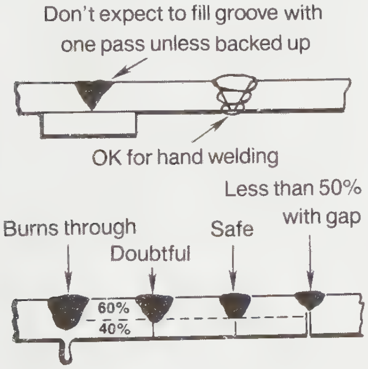
When designing joints to be welded, remember that the design will affect the weld. Joint design may limit process effectiveness or make some processes impossible to use. Joints also should be designed for easy access; inaccessible joints can reduce both productivity and weld quality.

Butt joints: These joints feature a bevel on the pieces to be joined, especially when the pieces are thick. The bevel angle determines the amount of weld metal in the joint. Smaller bevel angles require less metal. However, small bevel angles may make it impossible for some processes to fuse the root of the weld properly. This is remedied by making the weld root opening larger, but a large root opening will increase the amount of weld metal, defeating the purpose of the small angle.

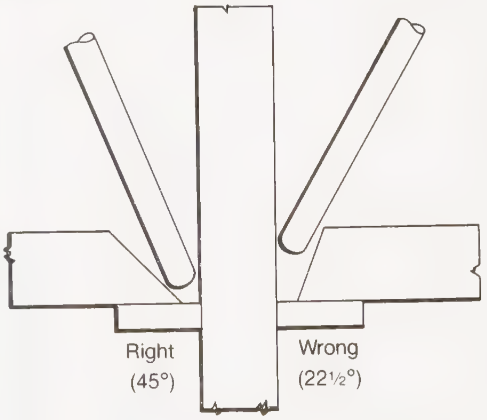
The less weld metal used, the better. Large welds increase both welding costs and the distortion caused when the weld shrinks on cooling. However, small root openings may require smaller-diameter electrodes, which can slow the welding process.

One-side welds: Open-root welds from one side must provide good fusion on the first pass, without burning holes in the bottom of the joints. However, single-pass welds requiring large amounts of filler metal often burn through. This can get worse when one of the base metals is relatively thin.

Designers can make life easier for welders by designing joints with backup bars, rather than using open-root joints. Backup bars provide a surface to weld against, letting welders do their job with less worry about burn-through. However, these bars often fuse to the weld. Metal bars can remain as part of the weld, but ceramic bars are usually chipped free.



Single-pass welds from one side will often burn through. Maximum safe penetration with one pass is about 60%, less when a gap is present. Reducing the amount of weld metal or using backup bars will avoid burn-through.



The bevel angle must allow the electrode to reach the joint root. Too small a bevel angle can require a small electrode and slow the welding process.

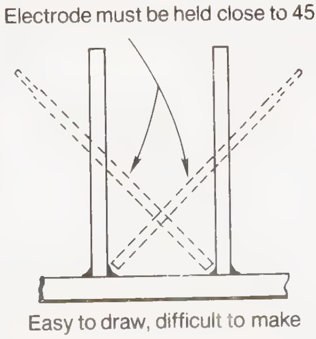
Penetration characteristics: Welding processes differ in penetration characteristics. If a very shallow-penetration process is used, such as shielded-metal arc welding with low-hydrogen electrodes, designers must adjust joints to make sure that they will fuse properly.

Productivity: Many engineers think welding productivity is measured in pounds of weld metal deposited per hour. However, the speed with which welders finish joints is more important.

Properly designed joints and appropriate processes do not require massive amounts of filler metal. Welders can complete joints quickly although the welding process in pounds per hour is relatively low. In fact, smaller welds can reduce distortion problems, cut labor and material costs, and help keep projects on schedule.

Accessibility: Welding machines and manual welders must have adequate access to the joints. The easier designers make it for the welders, the better the chance of getting quality welds. Designers also can sequence welding or specify subassemblies so welders can make simple welds in stages, rather than having to make difficult welds on a large assembly.

Many joints that look good on paper are difficult to weld. Accessible joints are easier both to weld and to inspect.


Electrode must be held close to 45°
Easy to draw, difficult to make

members.

When full-penetration joints through the thickness of the material are used, weld-metal strength must equal or exceed that of the base metals. Fillet welds must be appropriately sized to provide full strength. To determine adequate fillet size or depth of penetration, calculate stresses and joint loads, as well as the safety factor required. Designers often specify much bigger fillet welds than codes demand even with a safety factor. This adds to cost and distortion.

Use subassemblies: Whenever possible, large assemblies should be made in smaller sections before final welding. Subassemblies are easier to transport, position, and access for welding. They also permit some distortion control at intermediate stages of fabrication.

Process considerations

Engineers must not only consider design and material requirements, but also should take the actual welding process into account. Part positioning and welding procedures affect weld quality. Designers must compensate for distortions induced by welding. And once the parts are welded, they must be inspected. The quality of welds is ultimately the designer's responsibility.

Use jigs, fixtures, and positioners: Jigs and fixtures hold parts in correct alignment for welding. Fabrication shops may have suitable ones available, but when designers and manufacturing engineers have to specify new ones, this cost must be included in the cost of welding.

Motorized positioning equipment can turn massive components to position them for welding. If such equipment is available, workers must mount the components on the equipment and make sure that it is properly aligned before starting to weld. The time this takes must be compared to the welding time involved. If mounting time equals or exceeds the welding time saved, it is better to choose a welding process that will operate in the position the structure is already in.

Welding position is important. Thoughtful designers can arrange to have most welding done flat, so processes such as submerged-arc welding can be used. Flat-position welding is easier for welders, yields better quality, and improves production rates. Other positions limit the welding processes that can be used. The lack of access also makes inspection more difficult, and both quality and productivity are likely to suffer.

Specify welding procedures: Ideal welding procedures are those that produce acceptable-quality welds at the lowest overall cost. The procedures should be tailored to the application and should spell out exactly what welds are to be made and how they are to be made.

Procedure variables include:

- Welding process
- Welding conditions
- Welding operation details
- Joint details
- Filler metal and shielding gas (if any)
- Safety

Different procedures produce different weld qualities, such as strength only, commercial, or code quality. Strength-only procedures produce the highest welding speeds at the lowest costs. Appearance and quality are not important in these applications. Defects and imperfections are acceptable as long as the welds perform satisfactorily under service conditions. Tests should be specified to confirm performance of strength-only welds.

Commercial-quality procedures produce higher quality levels and appearance. Such welds are crack free and pressure tight. They look good and meet joint strength requirements. However, commercial-quality welds may have minor defects.

Code-quality procedures produce welds of the highest quality and best appearance. The welds are made under carefully controlled conditions and therefore are relatively costly to make. Commonly used codes include AWS Structural, AISC Buildings and Bridges, ASME Boilers and Pressure Vessels, and AASHTO Bridges.

Code-quality welds must be free of defects and pass nondestructive testing. In practice, this usually means welds that are free of cracks and have limited porosity, undercut, or other flaws.

Control and correct distortion: During welding, localized heating causes temperature variations, which may cause residual stress and permanent distortion. The designer must control and correct distortion. One of the best techniques to lessen distortion is restrained assembly, in which jigs or fixtures restrain the parts rigidly so they cannot move. This reduces distortion, but stress may build up within the joints, and may increase the chance of cracking.

Thin materials tend to distort more, so they should be restrained heavily. For example, clamp down 1/16-in. sheets as much as possible so they do not warp and buckle. They still will move when released from the jig, but less than if they were welded without restraint.

On thicker plates, welding sequencing controls distortion more effectively. Materials are allowed to move one way with one weld and to move back with the next. This movement minimizes distortion, but residual stresses in these joints still may be high.

WELDING INSPECTION TECHNIQUES

Several inspection techniques can find weld defects that are not apparent to the naked eye, but each technique has advantages and disadvantages. Techniques can be chosen for their cost, portability, speed, sensitivity, and accuracy. The material to be inspected may also factor in the choice of technique. No technique is likely to find every crack. The types of flaws expected may suggest one technique over another. In addition, different techniques require varying degrees of operator skill.

Ultrasonic testing is a common nonvisual inspection technique. Flaws as small as 0.001 in. reflect high-frequency sound energy. The intensity of reflections relates to the size of the defect, and the time delay of return is related to the distance of defects from the surface.

Ultrasonic testing equipment is relatively portable, and signal outputs can be electronically enhanced. The process is good for measuring depth and cracks that are perpendicular to the path of the sound waves.

On the other hand, ultrasonic inspection quality depends on operator skill and experience. Poor inspectors are likely to call out things that are not a problem or miss an actual problem. Ultrasonic inspection also does not readily differentiate between defects and surface irregularities. And most equipment does not produce a permanent record of the object inspected.

Radiographic testing relies on variations in the absorption of X-rays and gamma rays by different materials. X-ray film is placed behind the test object. The amount of energy that reaches the film varies depending on whether it passed through sound metal, inclusions, cracks, or pores.

Radiographic testing produces a permanent record of the test. The 2D image identifies the inspected objects, is sensitive enough to find small flaws, and records density related to discontinuity sizes.

Fastener finishes and coatings

Bright nickel	Most metals	Indoor excellent. Outdoor good if thickness is at least 0.0005 in.	Silver finish used for appliances, hardware.
Dull nickel	Most metals	Same as bright nickel	Whitish cast.
Passivating	Stainless steel	Excellent	Removes iron particles and produces a passive surface.
Phosphate bearing surfaces, DoD-P-16232, Type M	Steel	Good	Antichafing properties used on sliding or bearing surfaces.
Phosphate rupt preventive, DoD-P-16232, Type 2	Steel	Fair to good	Rustproofs steel. Plain grayish surface. Rust-preventive oils can be applied over it. Can be dyed black.
Phosphate paint-base preparations, Army 57-0-2, TTC-490, Type 4	Steel, aluminum, zinc plate	Good, after paint or lacquer applications	Plain gray. Prepares steel, aluminum, and zinc-plated parts for painting or lacquering. Increases bond between metal and coating.
Colored phosphate coatings	Steel	Superior to regular phosphated and oiled surfaces.	Increases corrosion resistance. Available in green, red, purple, blue, black, etc.
Rust preventives	All metals	Varies with function of oil	Various colors. Usually applied to phosphate and black oxide finishes to protect parts in transit or prolonged storage.
Silver plate	All metals	Excellent	Decorative, expensive. Excellent electrical conductor.
Electroplated tin	All metals	Excellent	Silver-gray color. Excellent corrosion protection in contact with food.
Hot-dip tin	All metals	Excellent	Silver-gray. Thickness hard to control, especially on fine-thread parts.
Electroplated zinc	All metals	Very good	Bright blue-white, gray coating.
Electrogalvanized zinc	All metals	Very good	Dull grayish color used where bright appearance is not wanted.
Hot-dip zinc	All metals	Very good	For maximum corrosion protection. Dull grayish color. Use where coating thickness not important.
Hot-dip aluminum	Steel	Very good	For maximum corrosion protection. Dull grayish color. Use where coating thickness not important.

All of these finishes require a coating of lacquer to prevent color change. *Indications are that the use of cadmium may be restricted.

Designers should also try to design parts so welds are made near the part's neutral axis, because weld-shrinkage forces away from that axis may cause angular distortion. Furthermore, if two equal-sized welds are made, they should be equidistant from the neutral axis, and done simultaneously whenever possible. Also, welds far from the neutral axis should be made smaller.

The presetting assembly method can also reduce distortion. Segments of a structure are prebent opposite to the predicted distortion to counter distortion in the complete joint. Weld shrinkage brings the segments to the desired position.

Distortion also can be reduced by avoiding overwelding, as well as by using subassemblies.

Specify heat treatment: Stress in most welded materials can be relieved by heating them while restraining them in the desired position. The weld materials relax, relieving some of the residual stress. However, the structures must be heated uniformly, and cooling must be slow so that stresses do not redevelop.

Stresses in large structures are not easily relieved through heat treatment. Local stress relief is sometimes possible but may be impractical due to the large heat sink afforded by these structures.

Stress relief is critical for dimensional stability in parts that will be machined. If structures contain much residual stress, they will move and distort when the machining process begins removing material.

Consider cleaning and inspection: Joints should be accessible not only for welding, but also for cleaning and inspection. Cleaning may vary from removing the slag covering to profiling the weld contour by grinding or machining.

Certain joints are inherently difficult to inspect. Design critical joints so they can be inspected with confidence. For example, fillet welds and spot welds are difficult to inspect. Full-penetration, butt-joint welds are much easier to inspect by standard methods.

Choosing fasteners

When the chosen joining method involves the use of fasteners, the choice of fastener can be as important to joint integrity as the joint design itself. Seemingly slight differences in the material used to make fasteners can greatly affect their performance.

Whether the fasteners used are threaded or nonthreaded, and especially when special types of fasteners are required, materials, finishes, and coatings should not be overlooked. They should be selected according to the joint requirements, just as the type of fastener is chosen. ■

Limitations of the technique include health hazards from X-rays and the skill required to interpret the film accurately. Internal discontinuities may be obscured by surface discontinuities. And to detect planar discontinuities, the X-ray beam must be closely aligned with such flaws.

Magnetic testing is done by inducing a magnetic field in ferromagnetic objects that are interrupted by discontinuities such as cracks. Disturbed magnetic field lines produce opposite magnetic poles on each side of the crack. These "magnets" attract particles that delineate the crack.

Magnetic testing is easy because the equipment is portable (welding power supplies are often the power source). Test results can be interpreted rapidly. The work often can be checked while it is still hot.

This method, however, can only test ferromagnetic material. Discontinuities must be oriented across the magnetic field lines, and the mobility of the particles must be good. This technique may also produce residual magnetism in the steel. In addition, crack widths cannot be determined. Because subsurface discontinuities produce diffuse indications, and metallurgical structure changes may give false indications, this process only detects surface or near-surface discontinuities.

Liquid penetrant testing locates discontinuities that are open to the surface of welds. A colored dye soaks into surface discontinuities. After 2 to 20 min, depending on the size and type of discontinuities expected, excess penetrant is removed, and the surface is dried. A developer — an absorbent white powder in a volatile liquid carrier — is applied. With time, the dye bleeds out from discontinuities and is visible against the developer-covered surface.

The process is inexpensive and portable. It detects very small discontinuities in a wide variety of materials, including plastics. However, such testing is limited to surface discontinuities. The dimensions of the indicators do not reflect the actual dimensions of the discontinuities, and this technique cannot be used while work remains hot.

Threaded fasteners

Many types of these common fasteners are available.

Hex and square nuts are the most commonly used varieties. Square nuts are normally used for lighter duty than are hex nuts. Flanged nuts have integral washers that simplify handling and may bridge oversized holes.

Several methods are used to prevent nuts from working loose:

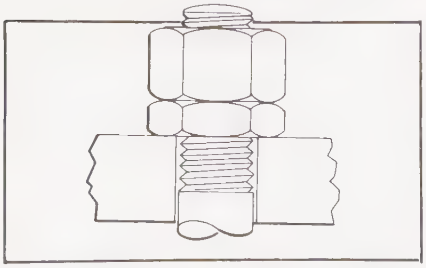
- Peening the bolt end which extends through the nut.
- Staking or deforming the nut threads.
- Using lockwashers.
- Using a jam nut with a regular nut.
- Providing special threads on both nut and bolt.
- Doping the mating threads with adhesives, lacquers, or special sealants.

Locknuts should be considered when:

- The joint is subject to vibratory or cyclic motion.
- Accurate preloading of assembly is difficult because of resilience of parts.
- Joint members are too fragile to withstand preload.
- Locking is preferred because of unknown service conditions.
- Accurate positioning of the nut along a threaded element is required, such as in spacer applications where parts must rotate without end play.

The four principal types of nuts which provide these locking features are jam nuts, castle or slotted nuts, free-spinning locknuts, and prevailing-torque locknuts.

Jam nuts

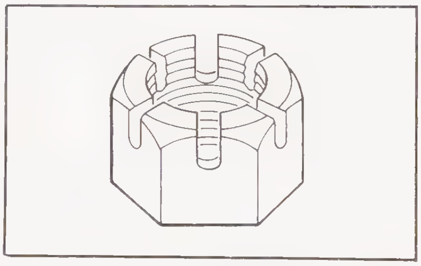


The jam nut is a thin nut, normally used under a full nut to develop locking action. Recommended practice is to torque the jam nut to seat only, then assemble a full nut on top of the jam nut and torque to full preload value while the jam nut is held stationary.

The same effect can also be achieved with two full nuts if preload must be developed when the first nut is tightened into position.

Castle and slotted nuts

Used primarily as safety nuts, these nuts are slotted to receive a cotter pin or wire which passes through a drilled hole in the bolt and locks it.



In assembly the nuts are torqued to preload value, then nut position is adjusted to line up the slots with the hole in the bolt. This is a disadvantage in critical-preload applications because of possible alignment variations which may lead to application of too much or too little torque.

Free-spinning nuts

The free-spinning locknut turns freely onto a bolt until seated against a base. Further tightening of the nut produces locking action.

Operating principles of all these nuts are similar. When the locking element engages the base surface, the spring of wedging action produced creates a tight friction grip against the bolt threads.

Unique nut designs are available to develop the locking action including:

- Two-piece nuts in which the elements distort each other or the bearing surface when tightened.
- Spring nuts which are notched or grooved to deform when seated.
- Insert nuts containing soft metal or nylon collars that deform to grip the bolt thread when tightened.
- Toothed nuts or nuts that have built-in toothed washers that engage and lock against the bearing surface. Some nuts may also cause a wedging action against the bolt threads.
- Special-thread nuts that obtain their holding power by deforming the bolt thread.

The free-spinning nut is advantageous where long travel under load is required to seat the nut. If pressure on the nut is not sufficient to develop locking action, the nut will turn freely into position without danger of damage to the locking feature.

Preloading is essential for all free-spinning locknuts to develop proper locking action. Except for two-piece nut designs, in which one nut element serves as the base surface for the other, free-spinning locknuts are not recommended for use on assemblies where there is relative motion between bolted parts, or in joints with multiple laminations that may relax bolt tension by embedding or plastic deformation. Use of these nuts should also be avoided with fragile parts.

Prevailing-torque locknuts

A built-in locking feature develops full locking action as soon as these nuts are engaged with the bolt threads. They must then be wrenched to final seated position.

Several of the locking techniques rely on a distortion of the nut thread or shape to create an interference fit. Metal or nonmetal inserts (plugs, strips, or collars) that plastically deform are also used to create an interference fit. Sometimes, separate locking pins, wires, or springs are fitted to the nut, or the nut may have a large slotted crown with springlike fingers that grip the bolt.

Ideally, prevailing-torque nuts should be used with the minimum thread engagement necessary to develop the holding strength of the nut and the locking action. Torquing these nuts over a long thread travel under load could damage the locking feature.

Prevailing-torque locknuts can also be used as spacer or stop nuts where components must be free to rotate without end play.

Captive nuts

Captive, or self-retained, nuts are multiple-threaded fasteners used on many thin materials. They are good in blind locations, and can generally be attached without damaging finishes.

Captive nuts can be attached in a number of ways and designers should consider what tools or systems are needed before selecting the fastener.

There are several categories of self-retained nuts. Plate or anchor nuts have mounting lugs which are riveted, welded, or screwed to the part.

Caged nuts use a spring-steel cage that retains a standard nut. The cage may snap into a holder or clip over a panel edge. These nuts come in strips up to 6 ft long for applications requiring fixed nuts in equally spaced sequences.

Clinch nuts have pilot shanks that are clinched or staked onto the parent part through a precut hole.

Other forms have a knurled or lobed base ring that is pressed into the panel, displacing the sheet metal to become self-retaining. Lobed types have a smooth sinusoidal lobe shape with a radius greater than 5% of the nut's nominal thread diameter. Such lobes meet the requirements of MS33588, and do not create stress risers in the parent material. Lobed nuts are available in standard and self-sealing versions.

Anchor nuts

Plate or anchor nuts have one or more lugs projecting from the base of the threaded body. The nuts are attached by riveting or welding the lugs to the work surface.

Plate nuts provide permanent attachment for threaded fasteners at inaccessible or blind locations. They assure positive positioning of the mating bolt and are self-wrenching. Plate nuts are preferred for stressed-skin applications because they do not introduce additional stresses around the bolt hole.

Riveting is most commonly used to attach plate nuts. Projection and spot welding are specified when it is desirable, for stress purposes, to minimize the number of drilled holes in the workpiece. The most common anchor nut is the two-lug plate nut, where the lugs protrude on either side of the nut body. A corner anchor nut has two lugs at a 90° angle.

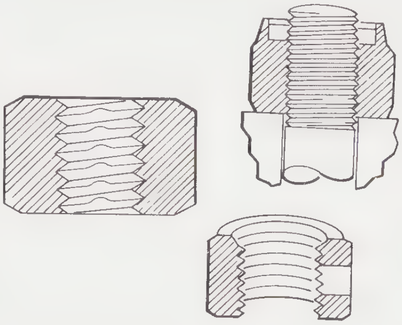
A number of nuts can be assembled on a single retainer, generally referred to as a "gang channel." Gang channels are produced in straight or curved lengths, with a variety of nut spacings.

Nonrotating plate nuts: These are used where little or no misalignment is tolerated. Bolts may be specified as regular-height nuts to use full bolt tensile strength. Low-height, lightweight designs may be selected for shear applications. Miniature designs are avail-

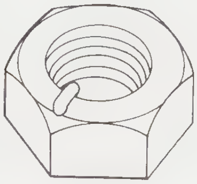
Prevailing torque

INSERT

Plastic or metal section is added to the nut to increase mating-thread friction. In most versions, a plastic (usually nylon) is added as a built-in washer, a plug through the side of the nut, or as a sprayed-on patch. Nylon is thought to provide damping action which imparts good vibration resistance. An insert may also be a soft metal such as lead. The added element plastically deforms when the nut is installed.

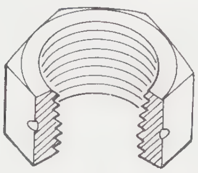


Metal-insert locknut has a projecting hardened wire or pin built-in to provide a ratchetlike locking action. Reuse is limited by wear of the pin tip.

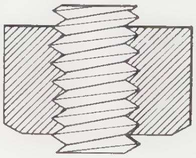


DISTORTED SHAPE

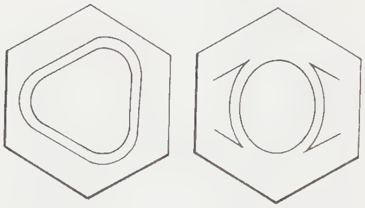
Distorted portion of nut thread produces an interference fit. Center dimple allows nut to be assembled with either side up.



Top-crimp nut is easy to start, but it must be properly oriented before assembly.



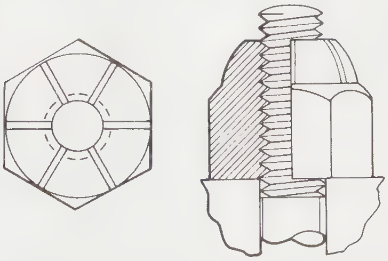
Nut hole, forced into an out-of-round shape after initial forming, produces spring action that maintains an interference fit after assembly.



Free-spinning

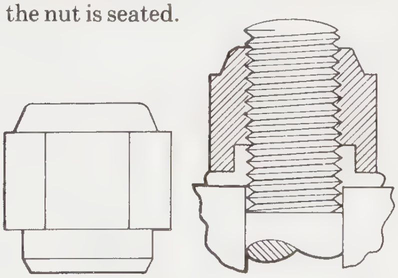
SLOTTED SECTION

Spring arms formed on the domed nut top are deflected inward. When the nut is threaded on, these arms grip the bolt threads.



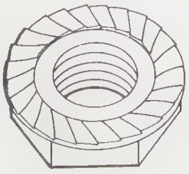
INSERT

A plastic or metal washer built into the nut base is permanently deformed and grips the bolt threads when the nut is seated.



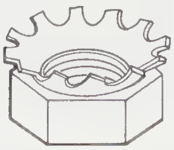
SERRATED FACE

Serrated or grooved face of nut digs into the bearing surface during final tightening.



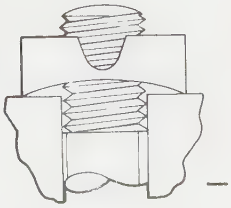
CAPTIVE WASHER

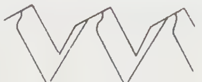
Toothed or spring washer attached to the bearing face of the nut increases friction between bearing surfaces.



SPRING HEAD

When fully seated, the concave portion of the nut is forced inward and clamps against the bolt threads.





MODIFIED THREAD

Nut threads have a modified cross section which crimps the bolt-thread crests when clamp load is applied.

Fairchild

Aerospace Fastener Division

Voi-Shan • Screwcorp • Tridair • Rosán • RAM

You'll find our fasteners on *every* major aircraft program begun in the last 30 years. Now we've consolidated our successful companies under a single name: Fairchild Aerospace Fastener Division.

Now you'll find the world's largest selection of high-performance aerospace fasteners and latches from a single source. Look to Fairchild for innovative engineering, quality manufacturing, competitive pricing and timely delivery.

Tridair Products

FlatBeam® Self-Locking Inserts
Mark IV™ Structural Panel Fasteners
Fasteners for Advanced Composites
KEENSERTS® Inserts and Studs
LiveLock™ Panel Fasteners
Self-Retaining Bolts
FlatBeam® Locknuts
QR™ Panel Fasteners
Adjustable Shear Alignment Pins
Captive Screws
Delron™ Inserts

Voi-Shan Products

Standard Bolts
Visu-Lok*
Eddie-Bolt® 2 Fastening System
Special Bolts
Visu-Lok® II*
Tooling
Eliptical Blind Nuts
Hi-Lok®/Hi-Tigue®
Composi-Lok® II*
Engine Nuts
Veri-Lite®
Taper-Lok®
Panel Fasteners
Titanium Bolts and Custom "Specials"

Rosán Products

Ring Locked Studs
Fluid Adapters
Slimsert® Inserts
Ring-Locked Inserts

Screwcorp Products

Externally Threaded Products Made to NAS and MS Standards

RAM Aerospace Mechanisms Products

High-Performance Structural Latches
Hold-Down Mechanisms for Avionics

Aerospace Tools

Providing Full Fastener Product Tooling Support

Call for Information and Quotes:

310-522-0700

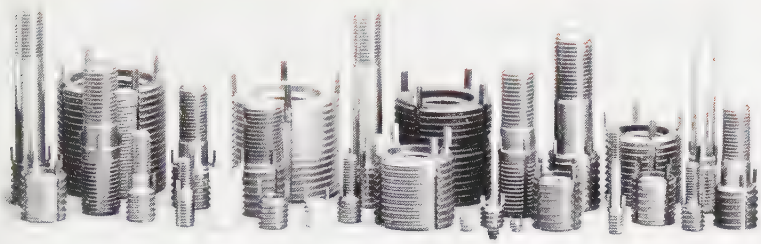
Fairchild

Aerospace Fastener Division
One Civic Plaza, Suite 500
Carson, CA 90745
310/522-0700 • Fax 310/522-7199

*Manufactured under license from Monogram Aerospace Fasteners

Join Forces Under a New Banner...

Tridair KEENSERTS® Inserts and Studs



Solid one-piece design provides permanent threads in virtually any parent material, with maximum strength and reliability.

- Standard KEENSERTS® Inserts and Studs. Tridair pioneered the design of this type of fastener and now offers the widest available choice of standard sizes, lengths, materials and types including: • Blind End Inserts • Hydraulic Inserts • Miniature Inserts • Shear-Load, Lightweight and Heavy Duty Studs • Solid Inserts • Floating Inserts • High-Strength Aluminum Inserts.
- Self-Broaching KEENSERTS® Inserts and Studs. Reduce time and labor during installation in hard, tough parent material.
- Metric KEENSERTS® Inserts and Studs. The most popular KEENSERT designs in hard metric sizes.

Voi-Shan Hi-Lok®/Hi-Tigue®

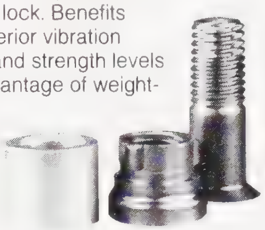
2-piece fastening systems designed for shear and tension applications. Each employs a threaded frangible collar with a regulated breakoff groove and a threaded pin. Installation is with industry standard hex key type tooling.

Hi-Tigue with controlled interference.

Hi-Lok with automatic torque control

Voi-Shan Eddie-Bolt® 2

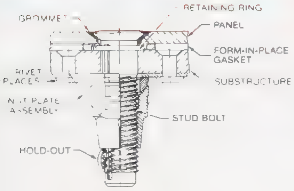
A high-performance pin system with either swage collar or free-running threaded nut assembly. A fluted pin thread provides a positive mechanical lock. Benefits include superior vibration resistance and strength levels with the advantage of weight-saving.



Tridair Custom Captive Screws

Supplied for all types of electronic packaging applications. Wide range of head styles, recesses, sizes, configurations and materials.

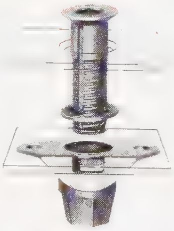
Structural Panel Fasteners



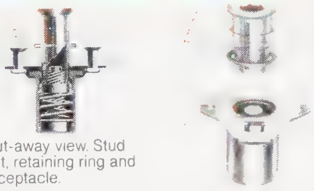
Complete Installation

Assure ultimate reliability for high performance aircraft.

Tridair Mark IV™ Fasteners



Tridair LiveLock® Fasteners



Cut-away view. Stud nut, retaining ring and receptacle.

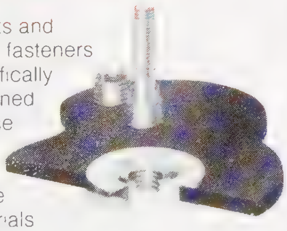
Feature spring-loaded ratchet design to insure positive locking and high cycle life.

Tridair QR™ Panel Fasteners

Low-cost, quick releasing panel fasteners.

Tridair Fasteners for Advanced Composites

Inserts and panel fasteners specifically designed for use in composite materials



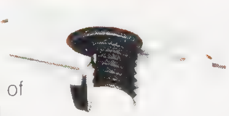
Tridair Delron™ Inserts

For honeycomb or sandwich panel fastening.

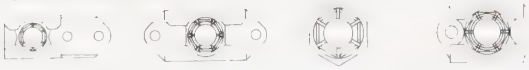
Wide variety of standard styles, or may be customized to suit specific applications.

Tridair FlatBeam™ Lock-Nuts

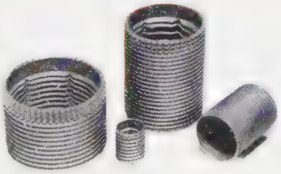
Maintain prevailing torque on bolt threads through a minimum of 250 installation and removal cycles. Thread Sizes: 3/16" to 3/8" plus Metric sizes.



Typical Configurations:



Rosán SlimSert® Inserts



One piece, thin wall threaded inserts which provide high strength threads in low strength materials.

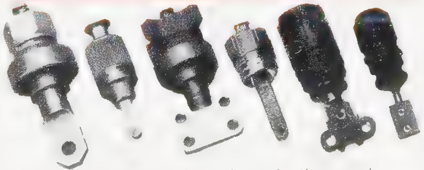
RAM Rexnord Aerospace Mechanisms, Inc.

High Performance Structural Latches

Examples:

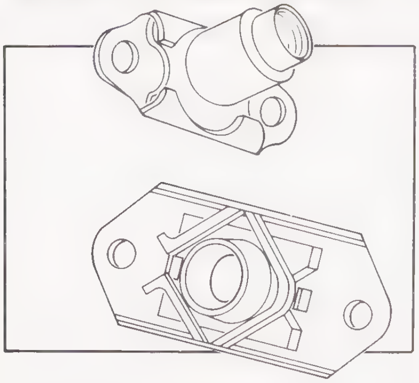
Custom devices designed to optimize performance for specific applications. Also available are Shear Pin, Tension and Multidirectional Latches.

Hold-Down Mechanisms for Avionics



Ergonomically designed ratcheting and lightweight hold-down systems for replaceable avionic black boxes and circuit boards. All meet or exceed military and commercial standards.

Circle 301



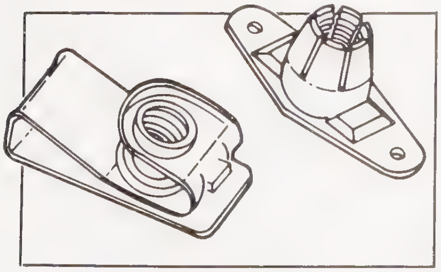
able for close-clearance installations. For safety, appearance, and sealing, capped nuts which cover the bolt ends are used.

For flush mounting, countersunk nuts are used with dimpled sheet metal to accommodate the screw head. Variable-depth counterbore nuts permit use of constant bolt lengths to fasten panels of various thicknesses.

Floating plate nuts: These nuts are used where bolt hole misalignment can occur in assemblies. Tolerances between holes can also affect alignment. Units with 0.015, 0.020, and 0.030-in. radial floats are provided for such misalignments. Oversize retainer holes facilitate assembly.

Swivel, or self-aligning, plate nuts are three-piece units consisting of a nut, concave or convex base ring, and retainer. These nuts simplify assembly of tapered or nonparallel components. The self-aligning design accommodates angular misalignment of mounting surfaces as well as some bolt-hole radial misalignment.

Floating, replaceable-element plate nuts: These multipiece units allow the nut element to be removed and replaced without disturbing the permanently attached retainer. They are usually high-performance nuts and are often specified for repeated use.



Clip nuts are sometimes used as plate nuts to eliminate riveting. They are self-retaining and easily installed and removed.

Plate nuts use the following locking techniques:

Nylon inserts are held like a washer in a cylindrical counterbore at one end of the nut. Walls of the nut are crimped or rolled over the washer to hold it firmly in place.

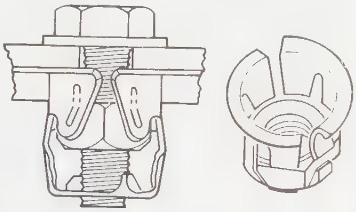
Elliptical offsets produce locking torque by deforming the reduced portion of the nut body. Usually, this portion is a turretlike section at the top of the nut.

Beam offsets contain multiple segments in the top portion of the nut which are bent inward, providing elastic interference with the bolt. A lubricant must be used with this type.

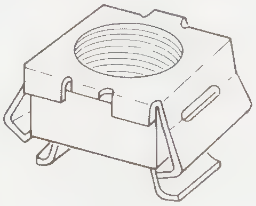
Plate nuts are not usually used in primary tensile applications. Most are specified as 125 or 140-ksi nuts. Some anchor, swivel, variable-counterbore and channel designs are rated at 160 ksi, and specials to 180 ksi.

CAGE NUTS

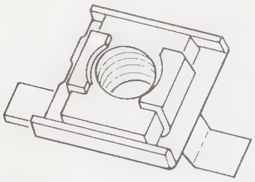
Heavy-duty caged nut: This is used in applications with round, blind holes. Driving the screw causes the locking lugs to engage.



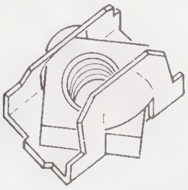
Full-cage retainer: Lugs are designed for use with thin sheet metal.



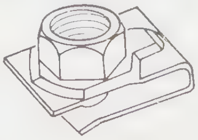
Square-hold cage nut: Lugs lock behind the panel.



Prevailing torque: Lugs engage and lock the screw thread.



Nut retainer: Design is used on panel edges.



Caged nuts

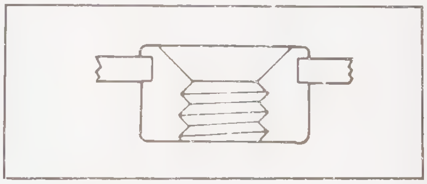
A multiple-threaded nut enclosed in a spring-steel retainer, this fastener has both the high strength associated with multiple-threaded fasteners and the versatility and self-retaining features of spring-steel fasteners.

Caged nuts are particularly useful in blind fastening locations. Their self-retaining feature eliminates the need for welding, clinching, or staking the nut in place. They can be installed after painting or coating, making masking or retapping unnecessary.

In some nut retainers, the multiple-threaded nut floats in the spring-steel cage, allowing enough tolerance to offset normal assembly misalignment. In types where the nuts are staked to the retainer, misalignment is accommodated by oversizing the mounting hole.

Clinch nuts

A clinch nut is a solid nut with a knurled or smooth shank or pilot projecting from one end. These shanks are inserted into preformed holes in sheet metal and spread, crimped, or rolled over, thus "clinching" them to the parent material. Clinch nuts provide multiple threads in materials too thin to be extruded or tapped.



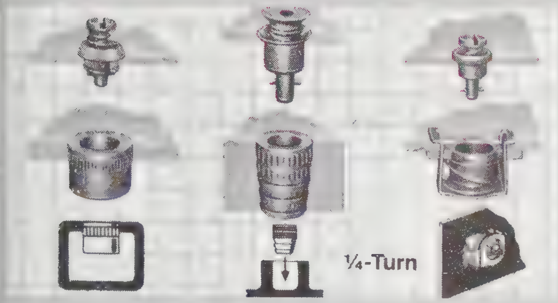
Clinch nuts use various configurations of pilot holes including hex, D-shaped, round and rectangular. The nut shank must be soft enough to roll over or be clinched by a tool.

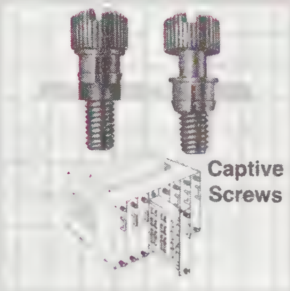
Self-clinching nuts

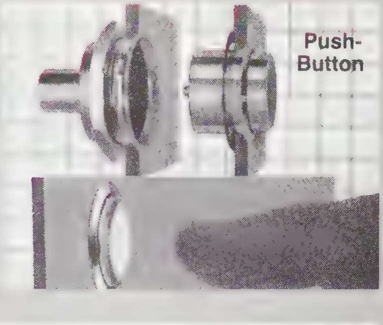
These nuts are squeezed into round, punched or drilled holes in sheet metal between a parallel punch and flat anvil. The nut is flush or less on the back side. No special hole preparation or tooling shape is necessary.

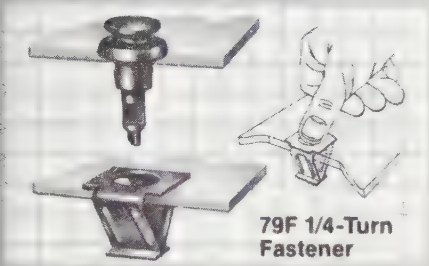
The self-clinching nut must be harder than the parent sheet material so that when it is squeezed into the sheet, the nut forces the sheet to cold flow into the undercut, locking the fas-

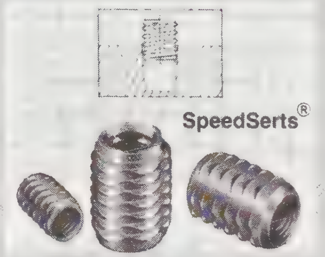
If the subject is fasteners, Camloc hears you talking.

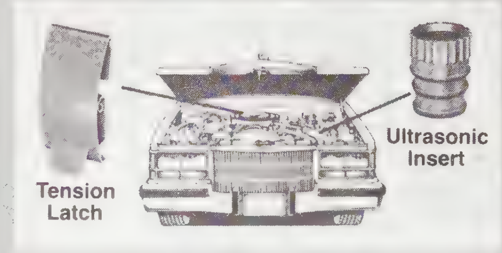










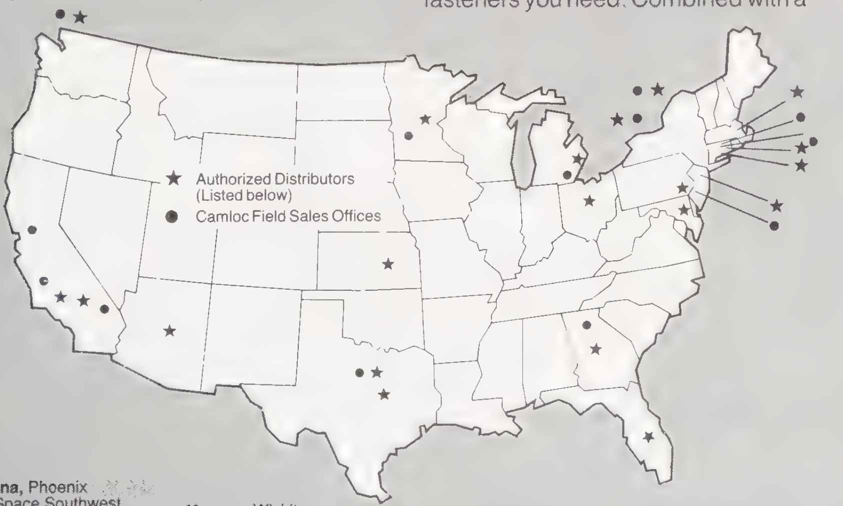


Fairchild/Camloc has been listening to your demands for ever closer ties with fewer, more dependable suppliers, and for greater involvement and personalized service from your distributors. We've been listening to your concerns about zero defect manufacturing, reliable sourcing, creative and timely customizing, and commitment to your survival in a competitive climate. We've been listening and acting!

That's why we've built a comprehensive network of highly skilled, technically trained distributors with extensive stocks of the Camloc specialty fasteners you need. Combined with a multi-million dollar finished parts stock at headquarters and our strategically located field engineering force, Camloc provides you with unmatched service and support.

Camloc distributors are different. You'll find them tuned in to "Just In Time" delivery requirements of the highest quality fasteners, latches, inserts and related components. You'll find them staffed with technical specialists who talk your language. Specialists able to provide quality control programs that comply with your specific requirements. Our distributors can help simplify your order processing, reduce your inventories...even custom-stock specialty fasteners to meet your individual needs and provide a host of value-added services to support your daily production and project life cycles.

No fastener manufacturer invests as much in you as Fairchild. Why not call a Camloc distributor, one of our field representatives, or our headquarters for your next fastener requirement and experience our unique commitment to service and quality. New catalog and list of authorized distributors upon request.


★ Authorized Distributors (Listed below)
● Camloc Field Sales Offices

Arizona, Phoenix
AeroSpace Southwest
1-800-421-3011
(602) 582-2779

California, Los Angeles
Barco Aviation, Inc.
(213) 207-0481

California, Chatsworth
Special-T Fasteners
(818) 998-1412

Connecticut,
Windsor Locks
Adams Industries
(203) 668-1201

Florida, Sanford
Engineering Fasteners
(407) 321-8000

Georgia, Alpharetta
J.O. King, Inc.
(404) 751-1875

Kansas, Wichita
Unirex, Inc.
(316) 685-5451

Maryland,
Gaithersburg
Capital Fasteners
(301) 948-9310

Massachusetts,
Wilmington
D.B. Roberts
(508) 658-7000
1-800-800-6887

Michigan, Livonia
Tri-West Products
(313) 422-7900
1-800-482-4160

Minnesota, Minneapolis
Aero-Space Computer
Supplies
1-800-234-4725
(612) 884-4725

New Jersey, Paramus
New York Fastener Corp.
(201) 265-8770

Ohio, Bedford Heights
Spencer Products
(216) 475-8700

Pennsylvania,
Bensalem
Aero-Missile Components
(215) 245-5700

Texas, Arlington
ASC Industries
(817) 640-1300

Texas, Grand Prairie
Central Industrial Fasteners
(214) 647-1191

CANADA
Ontario, Rexdale
Interfast, Inc.
(416) 674-0770

B.C., Richmond
Interfast, Inc.
(604) 273-0599

Quebec,
Pointe Claire
Interfast
(514) 426-2755

AUTHORIZED DISTRIBUTORS
★ **Authorized Distributors**
● **Camloc Field Sales Offices**

Fairchild

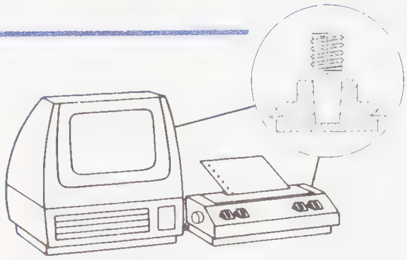
Camloc Product Division
Fairchild Fastener Group
601 Route 46 West
Hasbrouck Heights, NJ 07604
201/288-8300 • 201/288-8065

Camloc™ Fasteners for

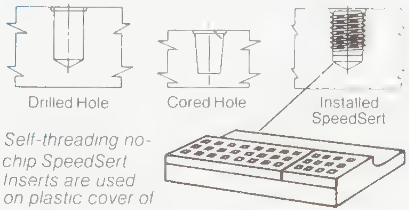
For Robotics to Radar

SpeedSerts® Inserts

Forms its own thread in plastics or light metal castings. Unique wave form threads assure chip-free installation. Stainless steel or brass. Bidirectional design eliminates need to orient each insert prior to installation. Self-locking and molylube versions. **Circle 681**



High-speed installed SpeedSert Inserts used on plastic CPU and printer enclosures of small business computer



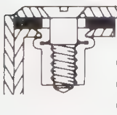
Self-threading no-chip SpeedSert Inserts are used on plastic cover of word processor keyboard where long-lasting threads are required

Circle 684

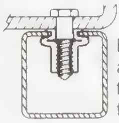
RivIT™ Inserts

High-performance design provides consistent pull-up and high torque-out values using standard round holes. No special hole configuration or keyways required. Ideal for use in square tubing or blind applications. Readily available in thread sizes from 4-40 through 3/8-24. Optional internal thread lock or blind end styles. Carbon or stainless steel. **Circle 682**

Typical Applications:



Mounting covers to electronic chassis.



Brackets attached to square tubing.

Camloc® CoilThread® Inserts

Low-cost helically-coiled 18-8 stainless steel wire inserts meet MIL/MS standards. Wide range of inch and metric sizes can be bulk- or strip-fed. Standard and self-locking versions can be installed with new externally adjustable power tool. Taps and gauges also available. **Circle 683**

High Security Key Locks and Key Switches

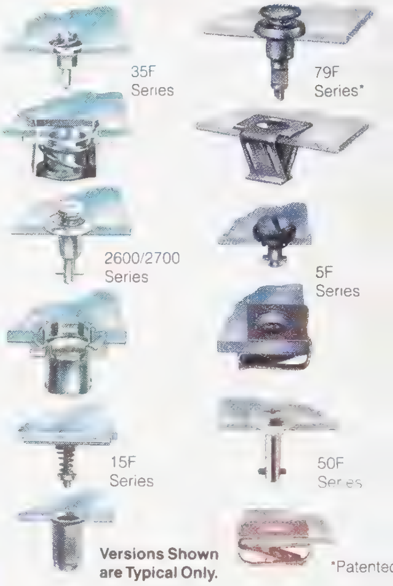
New Camloc high security tubular key locks and key switches* are available with notchless cylinders, drill-proof hardened steel construction, and seven-pin tumblers, minimizing potential danger from key duplication. In addition to the high security versions, a range of standard lock and switch sizes, styles, finishes/materials, and mounting features are available.

Circle 685

*An ABA product

Quick-Operating Fasteners

1/4-Turn Fasteners



Versions Shown are Typical Only.

*Patentec

Widest choice of quick operating, high performance fasteners for low installe cost. **35F Series.** Smallest 1/4-turn wit snap-in stud assemblies; various head styles. Clip-in, press-in and ultrasonic receptacles. **79F Series.** Snap-in stud and receptacles for low-cost installati Push stud to close; open with 1/4-turn. **5F Series.** Miniature hand-installed fastener. Ideal for chassis rails with prepunched holes. **2600/2700 Series** Widest selection of hand and tool-operated studs. Receptacles include ultrasonic and hand-installed types. **50F Series.** Quick installing, mid-size 1/4-turn fastener with snap-in stud an clip-on receptacle. **Circle 68**

Captive Screws

Quick and simple installation.

New Camloc® Press-in Captive Screws have hardened steel ferrules, and Camloc Flare-in Captive Screws have aluminum ferrules. Wide range of Camloc Snap-in Captive Screws for front or rear installation. They snap in place quickly with ordinary thumb pressure. Only a simple drilled or punched hole is required. Ask about our variety of head styles and finishes

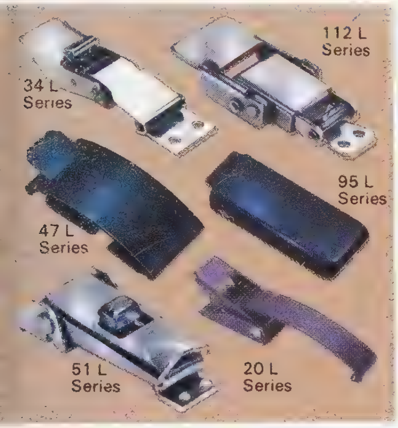
Circle 68

Electronic/Industrial Use

..from Industrial Machinery to Military Electronics

Latches

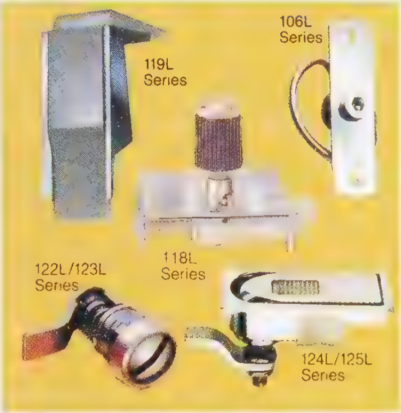
Tension Latches



34L Series. Miniature size; available with secondary lock. **112L Series.** Small, yet high strength (600 lbs.). Self-compensating for variable loads. **47L Series.** Low profile, large take-up. Styling characteristics of similar plastic versions but is trouble free. **95/96L Series.** Attractive style. Available in two sizes; numerous materials/finishes. **51L Series.** Adjustable series; over 200 variations: secondary locks, right angle bases, extended drawhooks, etc. **20L Series.** Medium duty latch. High strength to weight ratio.

Circle 688

Panel Latches

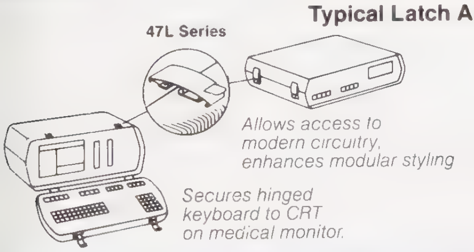


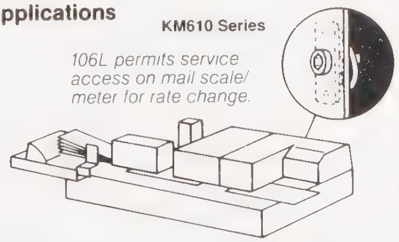
119L Series. Hand installed; requires only finger operation to open.
106L Series. Self adjusting pawl compensates for tolerances and gasket wear. Tool or hand actuator.
118L Series. 60° turn to open; slam to close. No strike required.
122L/123L Series. Fully assembled miniature pawl latch in snap-in and panel nut versions provide adjustment to compress RFI gaskets.
124L/125L Series. Flush latch with modern appearance, opens smoothly with slide trigger actuator for lifting and turning.

Circle 690

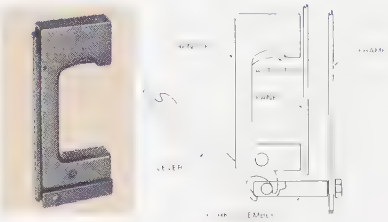
Versions Shown are Typical Only.

Typical Latch Applications

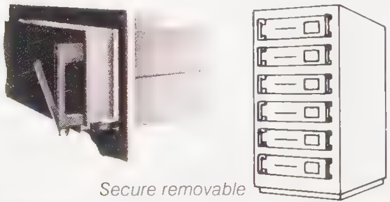

47L Series
Allows access to modern circuitry, enhances modular styling
Secures hinged keyboard to CRT on medical monitor.


KM610 Series
106L permits service access on mail scale/ meter for rate change.

Chassis Latches



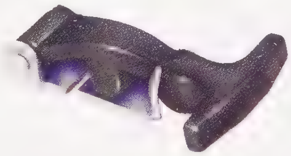
Provides mechanical advantage to engage and disengage drawer from pin connectors. Also function as carrying handles while securing chassis equipment.



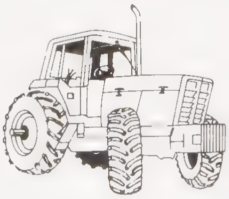
Secure removable electronic drawers

Circle 692

Rubber Latches



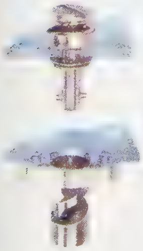
Three sizes available in different colors. Low or high modulus synthetic rubber compensates for severe misalignment, provides vibration and sound dampening. Ideal for hinged panels on farm equipment and plant machinery.

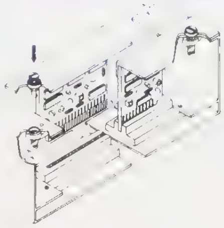


Rubber Latches hold down engine access door on tractor.

Circle 693

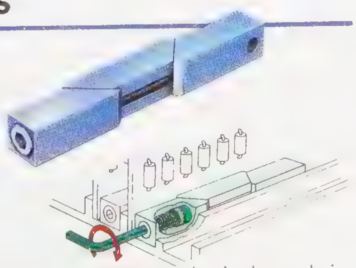
Printed Circuit Board Fasteners





Quick-operating, miniature **37F Series** secures printed circuit boards to rear connectors; opens and closed with ¾-turn.

Circle 689

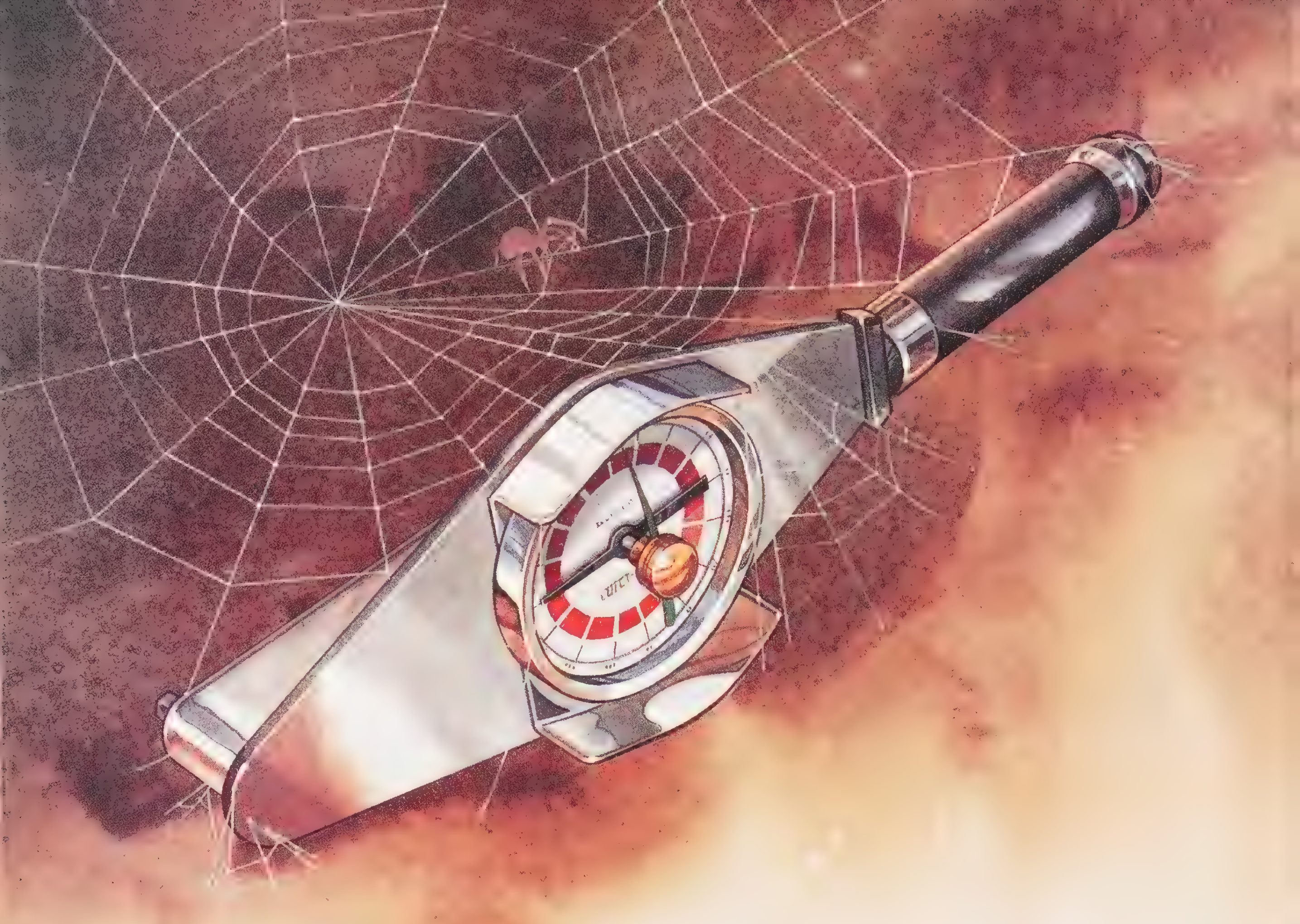


Wedg-tite™ Fastener locks boards in place without expensive torque wrenches; optional built-in torque limiter uses simple hex key; provides heat transfer between board and heat sink.

Circle 691

Fairchild

Camloc Products
Fairchild Fastener Group
601 Route 46 West
Hasbrouck Heights, NJ 07604
201/288-8300 • Fax 201/288-8065

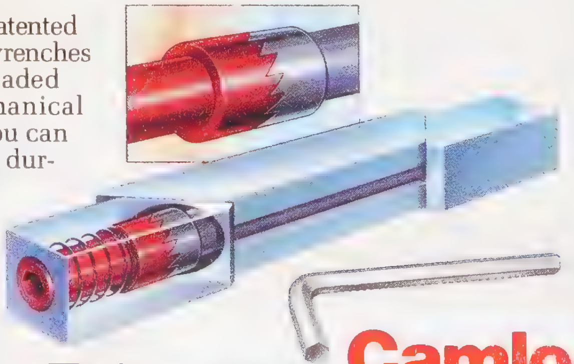


INTRODUCING THE WEDG-TITE™ PCB RETAINER WITH BUILT-IN TORQUE LIMITER.

(OUR APOLOGIES TO TORQUE WRENCH MANUFACTURERS.)

Thanks to our new Wedg-Tite™ retainer with patented torque limiting device, there's no need for torque wrenches to assure a specified load. Our special spring-loaded ratchet lets you know by audible click and mechanical release that the board is properly locked in. So you can be sure of constant force and heat dissipation, even during continuous vibration and jolting impacts.

For details on this and other unique designs for solving special problems, plus the latest on high-quality standard Wedg-Tite retainers, write or call today. And please give your torque wrench manufacturer our condolences.



Fairchild

Camloc
PRODUCTS
Products that matter . from people who car
Fairchild Fastener Group

601 Route 46 West • Hasbrouck Heights, NJ 07604 • 201/288-8300 • FAX 201/288-80

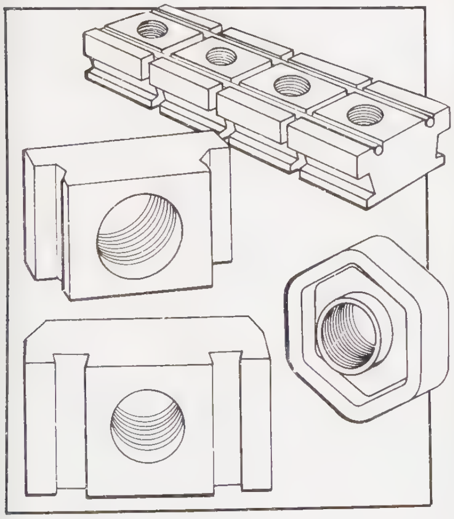
tener to the parent material. For most self-clinching steel nuts, the mounting material should be less than Rockwell B 80 in hardness.

Self-clinching nuts can be used in materials as thin as 0.03 in. and, with some small threads, as thin as 0.02 in. They are available as self-locking prevailing-torque types, floating types, floating self-locking nuts and flush-both-side types. The fasteners are made of heat-treated steel, stainless steel or aluminum. They can be used in metals that are unsuitable for welding. They should be installed after the parent metal is painted, plated or anodized. Self-clinching studs and standoffs are available as well.

Because self-clinching nuts fit into prepared drilled or punched holes, locating jigs and fixtures are not necessary. They can be installed with available automated installation equipment at great labor savings.

Pierce nuts

The most economical pierce nut is the universal one. Dies coin the metal and force it into nut undercuts. This nut is also available as a strip pierce nut in which strands of wire hold nuts together in a continuous strip. The nut strip simplifies automatic assembly by eliminating feed hoppers and nut orientation stations.



In the assembly operation, pierce nuts are fed continuously under a plunger. With each press stroke, the nut pilot is driven through the metal panel, piercing the mounting hole for the fastener. Clinching die ribs cold-flow the panel metal into the undercut, securing the nut to the panel. High-strength pierce nuts are used where greater stresses are encountered.

Pierce die nuts are designed for dynamically stressed applications. They have great resistance to pull-through, shear, and impact loads. Flush mounting makes the nut self-sealing.

Self-piercing nuts

These nuts are internally threaded, precision, work-hardened steel with external undercuts on two sides. Used in sheet-metal panels and installed by automatic machinery, they can be attached in open or blind locations. Self-piercing nuts have high resistance to torque, vibration, tension, and shear loads, and particularly to a combination of such forces.

Self-piercing nuts can either pierce and be clinched simultaneously, or be clinched into prepierced holes. Nut installation may proceed simultaneously with other forming, blanking, and piercing operations at high speed in both single and progressive die setups. The nut can be installed individually, in strip or coil stock, or as multiples in one panel.

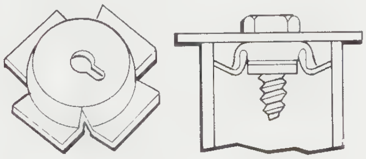
Standard self-piercing nuts may be installed in metal panels up to 0.145 in. thick. The work-hardened steel nut has a pilot-head hardness greater than Rockwell B 85. Proper malleability is retained in threaded areas.

Self-piercing nuts for flush mountings are available where thin metals and high stresses are factors. Application of the high-stress nut is generally limited to metal thicknesses of 0.03 to 0.09 in.

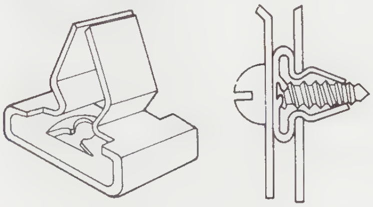
A locknut feature can be produced

SINGLE-THREAD NUTS

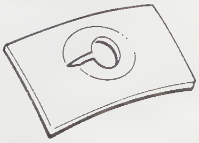
Tube nut: Components can be joined to tubes with this nut, which wedges within the tube. Various sizes are available to match tube ID.



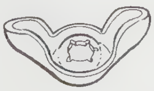
Spring arm nut: Arms expand when screw is threaded, locking the fastener in place.



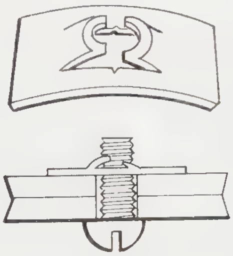
Dome nut: Nut has an opening which matches the pitch of the engaging screw. Advantages of this type of nut are high torque and 360° thread engagement.



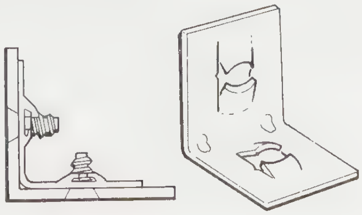
Wing nut: These are used in applications where frequent disassembly is anticipated.



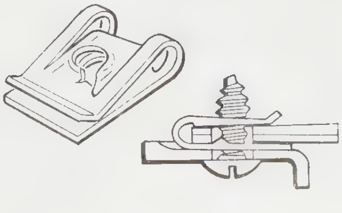
Flat type: This has prongs which engage the screw threads. Advantages include positive locking and vibration resistance.



Angle nut: This nut joins perpendicular panels quickly and easily combines the functions of three to six separate pieces.



U-type nut: This nut is used on panel edges to keep the screw perpendicular, preventing cross threading during assembly.



by projections on the driver (nut plunger). Controlled distortion of the last threads in the nut provides a locking action that can be made to torque requirements.

Self-piercing nuts can be installed in unplated, plated, or painted panels. Installation in a painted panel has little, if any, effect on the painted surfaces.

For proper torque resistance, a self-piercing nut should have an asymmetrical shape. A pilot should protrude a minimum of 0.005 in. through sheet metal to ensure proper slug removal. When piercing two metal thicknesses, the pilot should protrude a minimum of 10% of the total maximum thickness of both metals.

Self-piercing nuts can be located on 1.5-in. centers with standard tools, or closer with special tooling. Rotation of the nut on the panel allows some deviation in the center distances.

When the pilot protrudes through the panel metal, the nut should be placed in an embossment great enough to place the pilot surface of the nut 0.010 to 0.020 in. below the mating-part surface.

Single-thread nuts

Single-thread-engaging nuts are formed by stamping a thread-engaging impression in a flat piece of metal. They are used for lighter-duty applications than multiple-thread nuts of the same size. These fasteners reduce costs when used in place of ordinary fasteners. They eliminate several assembly steps and reduce the required number of parts.

Unlike multiple-thread nuts, single-thread types do not require a large amount of torque. Their holding power and resistance to vibration loosening depend solely on spring action.

Because only one screw thread is engaged at a time, the prongs cannot "freeze." This can be important in applications where fasteners are exposed to corrosive conditions, and ease of removal is a factor.

Single-thread-engaging nuts will withstand greater tensile loads when screw holes have minimum clearance. (This does not apply to the self-retaining type where part of the nut snaps into the clearance hole.)

The proper machine screw length to be used with single-thread nuts is determined by the general practice used with conventional threaded nuts: Allow one thread to protrude beyond the thread-engaging element of the fastener. However, sheet-metal screws that taper at the end should protrude a minimum of three threads beyond the thread-engaging element to assure engagement on the full screw root diameter.

It is possible to design this fastening device in almost any physical shape. The helically formed prong and truncated-cone types are best used as nuts into which the screw is driven. Spirally formed thread-engaging elements can be stamped into hexagonally formed nuts, acorn locknuts, washer nuts, and wing nuts. Single-thread-engaging spring nuts can also be furnished with preassembled clinched screws.

Because of their spring lock and resistance to vibration loosening, single-thread nuts eliminate the need for lockwashers. In addition, their design versatility makes them valuable in blind fastening locations, and multiple fastening locations.

Inserts

Inserts act as a tapped hole in both open and blind locations. They provide a strong, wear-resistant anchor for a standard screw in weak materials that do not have the shear strength to withstand desired fastener loads alone.

Typical applications include soft materials such as plastics or fiber board, wood, molded or die-cast parts, difficult to tap materials such as very hard metals, and materials where it is important not to damage the parent metal.

Inserts can offer more precise threading to conventionally tapped holes, provide a thread-locking feature in hard materials, or repair tapped holes.

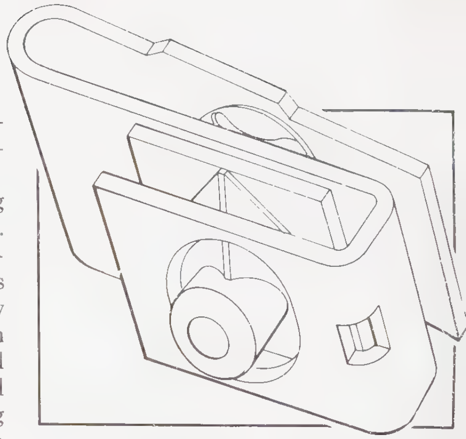
Categories

Inserts are classified as two general types: those held in place by external threads and those that use some means other than threads (knurls, grooves, interference fit) for their holding power.

Externally threaded inserts can be further divided into three types:

Wire-thread inserts: These precision coils of diamond-shaped stainless wire form both internal and external threads. They are screwed into pretapped holes to provide an accurate standard internal thread for screws, bolts, or studs.

Solid self-tapping/self-threading inserts: These thread-cutting or thread-forming external threads are for use in either drilled or cored holes. The thread-cutting types have thread interruptions on the external threads in the form of slots or holes to provide cutting edges similar to a tap. Thread-forming types have external thread shaped in a series of lobes to form threads in the base material. Self-threading types create no chips.



For rapid assembly of thin sections, the stamped retainer may provide an ideal solution. They can be manually or automatically slipped in place with no part preparation. Some have strong prevailing torque capability that keep screws in place under vibration.

Solid bushing: These inserts use a number of locking techniques to match most situations. One version has built-in locking keys that are driven in after the insert is in place to provide rotation resistance. Other two-piece inserts have a separate key ring or serrated locking ring to provide the torsional resistance.

Modified or distorted external-thread inserts are used to create an interference fit with the tapped hole through a swaging action. Nylon plugs and strips attached to inserts may also provide locking action.

Inserts without external threads used in drilled or cored holes include these types:

Molded-in inserts: Used in thermosets, thermoplastics, rubber, and ceramics, they have one or more external knurled sections. Cast-in inserts, which are similar, are used on nonferrous metals.

Pressed-in inserts: These have external retention rings, knurls, or other elements for locking the insert in the base material. Some designs have slotted segments that are forced into the hole when the fastening screw engages the internal thread. Others have integral washers or cones that expand the locking segments as the insert is driven into the hole.

Ultrasonic inserts: Solid bushings with annular and longitudinal grooves prevent both pullout and rotation after installation. These are used only on thermoplastics.

Sandwich-panel inserts: These are used on honeycomb and composite sandwich panels, in either one or two-piece construction. The one-piece type

All 15,000 Tinnerman® standard fasteners hold down the same thing.

Cost, of course.

See, every time we don't have to re-invent the fastener, you save the expense of the designing and tooling.

You save the time required for designing and tooling, too.

And you save yourself some worry, since our single-piece, multiple-functioning and complex-assembly fastener designs are proven reliable through years of use.

So when you need vibration resistant steel or plastic fasteners, talk to us about Tinnerman® brand fasteners.

Just write: Eaton Corporation, Engineered Fasteners Division, Service Center, P.O. Box 6688, Cleveland, OH 44101.

The important thing isn't that we've got more standard fastener designs than anyone else. It's that you pay less.

Circle 306

EATON

is usually applied on one side of a panel with a potting compound to obtain the required strength. The two-piece construction is usually swaged together with some interlocking feature and applied through both sides of the panel.

Specialty inserts are available that provide an external male thread, or other fastening means. One insert is the stud insert. This may have any of the previously listed holding and locking configurations on one end and a standard thread on the opposite end.

Design factors

These requirements should be considered in selecting the best insert: shear strength of parent material, operating temperature, load requirement, presence of vibratory loads, ease of installation, and installed cost.

Boss radius and edge distance: The distance from the center of the hole to the nearest edge is usually equal to the insert OD. Brittle-material inserts that produce high installation stresses may require greater edge clearance.

Material thickness: For blind holes and through holes, hole depth equal to the insert's nominal length is generally needed. When inserts are installed in cored, drilled or tapped holes, hole depth is usually greater than the insert nominal length. Drill point depth, length of tap chamfer, space for chips from self-tapping inserts, and clearance for the installation tooling should be considered.

Floor thickness: The dimension from the bottom of a blind hole to the far side of the material must be adequate to withstand the various machining and insert installation forces. Porous materials must be thick enough to prevent leakage if a leakproof assembly is required.

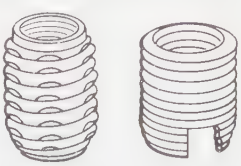
Locking: Assemblies subject to shock and vibration should be protected by inserts with screwlocking features. Locking adhesives may also be used.

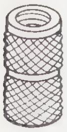
Metallic locks work by using a deformed portion of the insert's internal threads that provides a controlled interference fit to the mating screw. Wire-type inserts have a polygonal resilient coil, while solid inserts have internal threads that are deformed by one or more indentations on the outside of the insert. Reusability with metallic locks is good, with customary life beyond 15 cycles. Some versions can be used for service temperatures up to 1,200°F.

Nonmetallic locks generally incorporate a fiber or plastic (usually nylon)

COMMON INSERTS

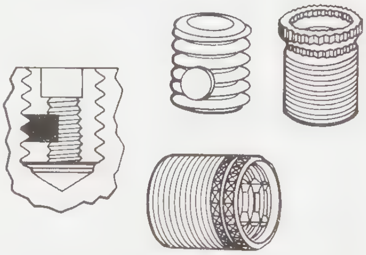
Self-tapping/self-threading: Used chiefly on nonferrous metals and plastic materials, they eliminate the need for a separate tapping operation. Interference fit produced by the cutting action locks the insert in place. Nylon plugs or strips, or distorted threads, may be used to gain additional holding strength. Internal-threads may also have locking capability. They can be used with both thermosetting plastics and thermoplastics. A thread-forming version for softer materials generates no material cuttings. Several types are symmetrical in design to allow high-speed automatic installation.

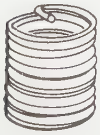




Molded-in: These are used where design and production considerations make it practical to have the insert cast in place when the part is formed. This type is frequently used with ceramics, rubber, and thermosetting plastics. Insert base is frequently knurled or knurled and grooved. Pullout torque is usually higher in plastics than with self-tapping or ultrasonically installed inserts.

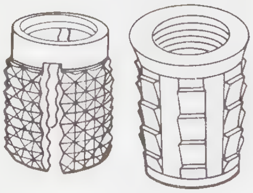
Solid bushing: These inserts are installed in any material that can be drilled and tapped. They are held in place by mechanical locks such as built-in or separate locking keys and locking rings, or by the swaging action of knurls or strips. Solid bushings may also have internal thread-locking features to help secure the screw.



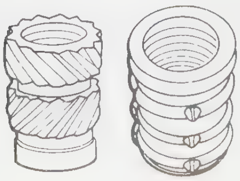


Wire thread: Used for tapped hole repair and to provide a strong thread in softer metals such as aluminum, these are inserted with a special driving tool. The tang is broken off after installation. Where vibration or shock is a problem, distorted thread locking is recommended.

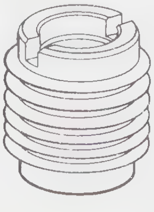
Pressed-in: Also known as knurled, press-fit, or expansion inserts, nonthreaded inserts require a prepared hole slightly larger than the insert OD. This type is the easiest to install. It is used chiefly for lightly loaded applications. A variety of techniques expand the insert after it is in place.



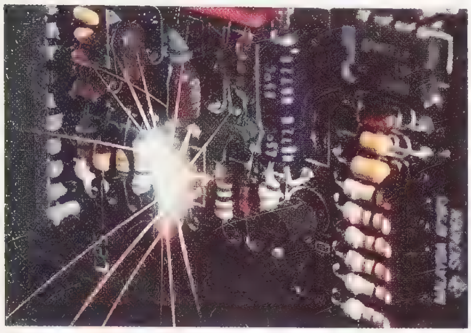
Ultrasonic: Used with thermoplastics, these inserts require a prepared hole. Friction from vibration melts a small area which solidifies to lock the insert in place. Holding power may be less than that achieved with molded-in inserts.



Knife thread: Primarily for use in wood, knife threads slice wood fibers, providing a strong joint. These inserts are installed with a screwdriver that fits the slot at the top.

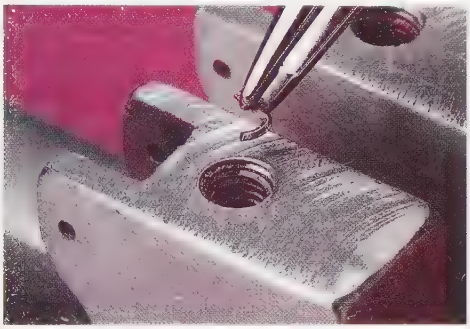


When Camloc® eliminated the tangs from CoilThread® *II* Inserts, they also eliminated…



this

The possibility of loose tangs short-circuiting valuable electronics. CoilThread II Inserts are FOD-free (foreign objects and debris)!



and this

The need to break off and remove tangs after insert installation. A process that costs up to 50¢ per hole!

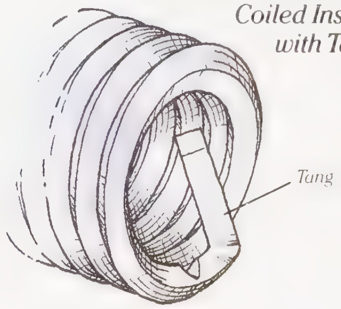
and this

The need to account for all loose tangs during assembly. You can't lose what you don't have!

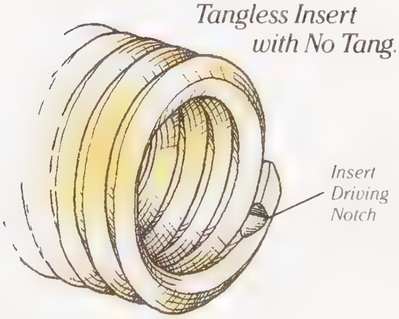
and this

The damage to expensive castings caused by outmoded insert removal techniques. Camloc's new tool never touches the casting.

Traditional Helically-Coiled Insert with Tang.



New CoilThread II Tangless Insert with No Tang.



With CoilThread II Inserts, there are no tangs to break off, remove…*or lose!* They set a new standard for high-speed, low installed-cost threaded inserts. Send for the new CoilThread II Insert brochure and free samples today.

Fairchild

Camloc Products
Fairchild Fastener Group
601 Route 46 West
Hasbrouck Heights • NJ 07604
201/288-8300 • Fax 201/288-8065

Send Salesperson: Circle 694
Send FREE Brochure & Samples: Circle 695

How CoilThread II Inserts Install Without Tangs

Here's where CoilThread II Inserts really stand out from all other helically-coiled inserts. Instead of a tang, these new inserts feature a unique, ramped driving notch on the inside diameter of the first coil on each end of the insert.

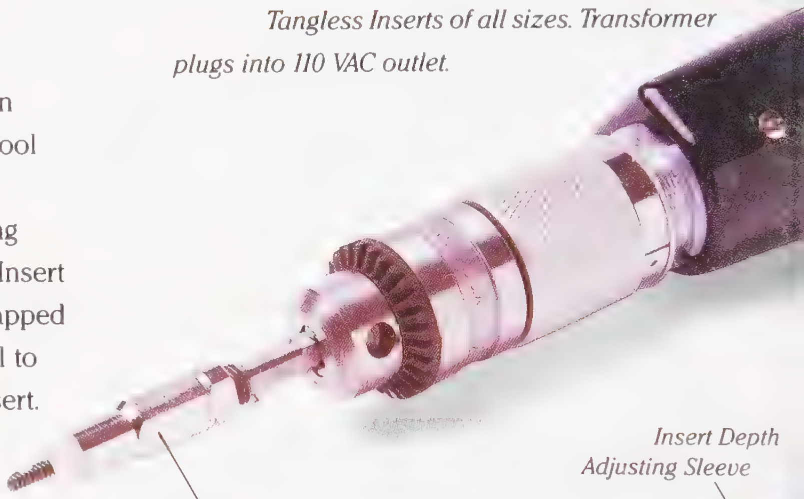
To drive the insert Camloc developed an innovative, electrically-powered installation tool with a patented, internal, spring-loaded pawl located at the tip of the tool's mandrel. During installation, this hooked pawl locks into the Insert Driving Notch and rotates the insert into the tapped hole. The pawl then retracts into the mandrel to allow the tool to back out of the installed insert.

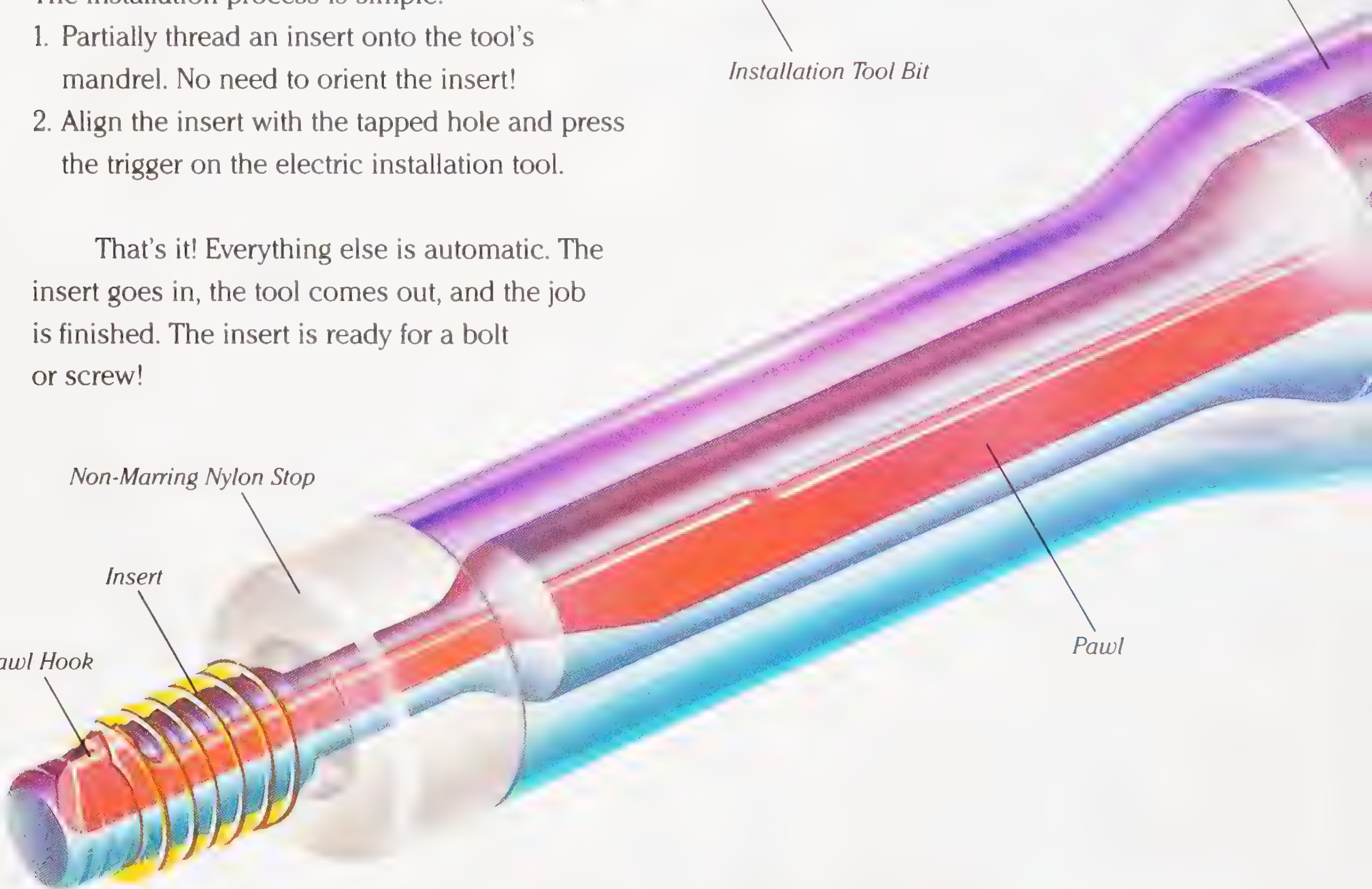
The installation process is simple:

1. Partially thread an insert onto the tool's mandrel. No need to orient the insert!
2. Align the insert with the tapped hole and press the trigger on the electric installation tool.

That's it! Everything else is automatic. The insert goes in, the tool comes out, and the job is finished. The insert is ready for a bolt or screw!

U.L. approved, power tool ac
installation tool bits for CoilThread II
Tangless Inserts of all sizes. Transformer
plugs into 110 VAC outlet.





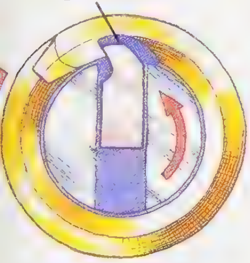
Innovative installation tool bit features an internal, spring-loaded pawl to drive inserts. Insert depth is set by rotating the adjustable sleeve.

Quick, non-destructive removal.

Forget the crude, time consuming and sometimes destructive methods used to remove conventional helically-coiled inserts from expensively prepared castings.

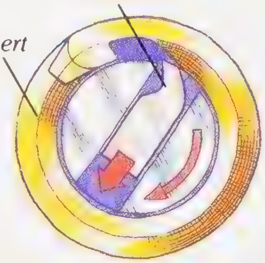
Removal tools
for conventional inserts.

End view
uring insert installation.



The spring-loaded
awl within the instal-
ation tool engages the
ving notch to install the
CoilThread II insert.

End view of tool
leaving installed insert.



Once the insert is driven to the proper depth, the installation tool automatically reverses rotation. The pawl slides back into the tool's recess as the mandrel unscrews from the installed insert.

CoilThread II
Insert removal
tool.

CoilThread II Tangless Inserts provide a safer, more foolproof solution. A specialized removal tool bit utilizes the Insert Driving Notch to grip the insert from the inside thread and spin it back out. No harm, no foul; expensive castings are left untouched and undamaged!

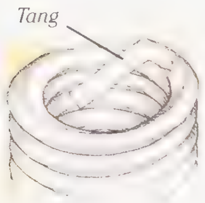
Camloc Products
201/288-8300 • Fax 201/288-8065

Send Salesperson: Circle 694

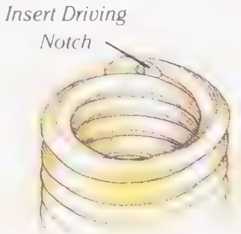
COILTHREAD II INSERTS: THE FIRST MAJOR IMPROVEMENT IN HELICALLY-COILED INSERTS IN MORE THAN 50 YEARS!

We've eliminated the tangs.

Conventional helically-coiled inserts need tangs for installation. But once installed, loose tangs become potentially hazardous. They require special tools, time consuming breaking off and removal, and careful watch. Even with care, tangs still have a habit of disappearing into expensive equipment, often showing up later causing considerable damage to electrical and mechanical components. In some applications, every tiny, loose tang has to be carefully accounted for.



Traditional Helically-Coiled Insert with *Tang*



New CoilThread II Insert without *Tang*

But you can't lose what you don't have, so Camloc eliminated the tangs altogether. With patented CoilThread II Tangless Inserts you'll never have to remove or look for another lost tang. And every minute you're not looking for tangs is time towards increased productivity and increased profits.

Small yet potentially disastrous. More than a nuisance to remove, lost metal tangs sometimes turn up to disable expensive electronic or mechanical components in critical avionics and computer assemblies.

There's no 'wrong' end to use.

CoilThread II Tangless Inserts are the first and only bi-directional, helically-coiled inserts available. They have an Insert Driving Notch at *both* ends, so the time-consuming task of orienting each insert before installation is eliminated. Not only can they be installed with your eyes closed, they're also the only helically-coiled inserts well suited for fully automated assembly.

CoilThread II Tangless Inserts meet or exceed all applicable MIL specs.

Camloc has spared no effort to make CoilThread II the ultimate in helically-coiled inserts. They are designed to replace helically-coiled inserts as specified per MS122076 and MS124651 series (standard thread) and MS21209 (locking thread); they install in standard STI tapped holes per MS33537. Final assembly meets the requirements of FED-STD-H28 and will accommodate standard bolts or screws (MIL-S-7742) or UNJ (MIL-S-8879). The 18-8 stainless steel material is the same as that of regular helically-coiled inserts meeting AMS 7245 and MIL-I-8846. Locking versions meet or exceed the pertinent specifications of MS21209 and MIL-I-8846.

Appropriate documentation for CoilThread II Tangless Inserts has been submitted to government agencies for inclusion in current specifications covering wire-formed inserts.

CoilThread II Tangless Inserts and Tools are currently available in the following sizes: 2-56, 4-40, 6-32 and 8-32.

Camloc Products 601 Route 46 West • Hasbrouck Heights • NJ 07604 • 201/288-8300 • Fax 201/288-8065

Send Salesperson: Circle 694
Send FREE Brochure & Samples: Circle 695

pellet, strip, or collar that forces the mating screw into a frictional lock with the internal thread of the insert. The upper temperature limit is 250°F.

Anaerobic adhesive can be applied to insert threads as a liquid. The locking fluids crystallize to a hard plastic in the absence of air and bond the interfaces together. The hardened plastic must be sheared to separate the parts. Upper temperature limit using this method is 400°F. Other thread-locking adhesives may also be used.

Temperature and cold flow: If the parent material expansion rate is greater than that of the insert, some relaxation or clearance can develop. High operating temperatures may reduce the shearing strength of the base material.

Cold flow or yielding of the parent material over a period of time, especially under load, also affects the insert retention force.

Bolts, screws, and studs

Bolts are usually defined as a threaded fastener intended to be mated with a nut, while a screw can engage either preformed or self-made internal threads. Bolts and screws share a number of head shapes and drive configurations. Bolts which have a shank configuration preventing rotation cannot be considered — or used — as a screw. Conversely, fasteners with cutting or tapered threads not intended to mate with a nut, such as self-tapping screws, cannot be used as bolts. A stud is an externally threaded headless fastener. One end usually mates with a tapped component and the other with a standard nut.

Captive screws

Fasteners that remain attached to the panel or parent material, even when disengaged from the mating part, are captive screws. They are used to meet military requirements, prevent screws from being lost, speed assembly and disassembly operations, and prevent damage from loose screws falling into moving parts or electrical circuits.

Methods used to attach captive screws to the parent material include: split washers clipped on after the screw has been inserted in the panel; threaded panel holes used in conjunction with a screw that has an externally relieved shank, a long groove between the head and threads; or a ferrule or sleeve that is pressed, threaded, swaged, or flared to the parent material.

Captive screws are available with either inch or metric threads, and with most of the common finishes and head styles available in ordinary machine screws. Because there are no universally accepted standards for captive screws, many apparently similar captive screws are not interchangeable with each other.

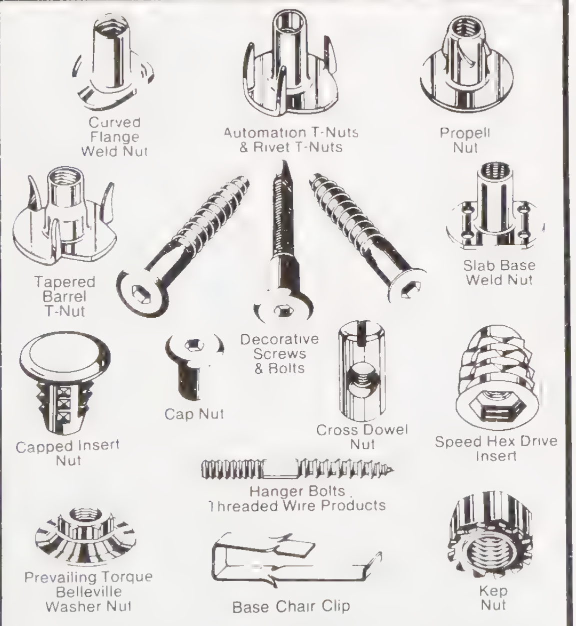
Tapping screws

These screws are used to cut or form a mating thread when driven into preformed holes. They permit rapid installation, since nuts are not used and access is required from only one side of the joint. The mating thread produced by the tapping screw fits the screw threads closely, and no clearance is necessary. Tapping screws are used in steel, aluminum, die castings, cast iron, forgings, plastics, asbestos, and resin-impregnated plywood.

Standard tapping screws

The basic tapping screws are classified as thread forming and thread cutting. Thread-forming tapping screws

The Right Connection™

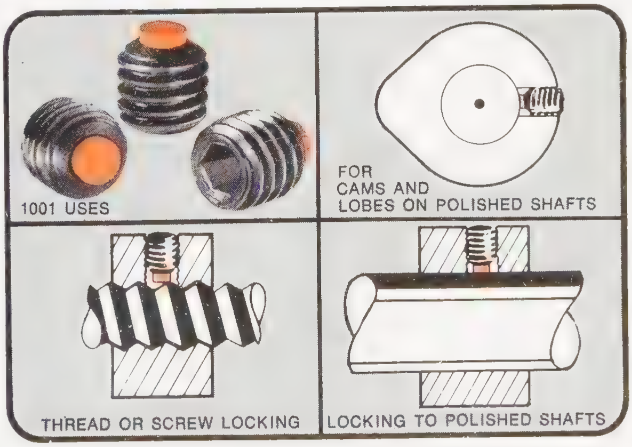


Total Commitment to Customer Service Since 1958
Quality Assurance • Competitive Prices
On Time, In-Stock Deliveries
National Distribution Service Centers

Stafast Products Inc.
505 LAKESHORE BLVD. • PAINESVILLE, OHIO 44077
(216) 357-5546 Outside Ohio Toll Free 800-782-3278

Circle 311

TRY these new brass or nylon tip set screws FREE!


1001 USES
FOR CAMS AND LOBES ON POLISHED SHAFTS
THREAD OR SCREW LOCKING
LOCKING TO POLISHED SHAFTS

Brass tip hex socket set screws by Lexington have hard, fully heat-treated steel bodies, soft brass tips. Also available with nylon tips on stainless steel bodies. Both types lock tight—will not mar surface of mating part.

Over 80 standard sizes, ranging from #2-56 through 1″-8, are available for immediate shipment from stock.

Test these brass or nylon tip socket set screws yourself. Send for free sample, along with catalog and prices—today.

The Lexington Company
P.O. Box 300-D, Eden, N.Y. 14057 • (716) 992-3425

Circle 312

displace the material adjacent to the pilot hole so it flows around the screw threads. Generally, they are used where large internal stresses are desirable to increase resistance to loosening. The mating parts create a fit with zero clearance, since no material is removed from the engaged section. Lockwashers or other locking devices are usually not needed.

Thread-cutting tapping screws have cutting edges and chip cavities that create a mating thread by removing material from the engaged section. These screws are applied in materials where disruptive internal stresses are undesirable.

Tapping screws are available in coarse and fine-thread series. Coarse threads should be used with weak materials. Fine threads are recommended if two or more full threads of engagement must be above the top of the cutting slot, but the thickness is insufficient to allow two full threads of the coarse-thread series.

High-performance, thread-rolling tapping screws are used with thicker-gage metals, such as steel, brass, zinc, and aluminum forgings and castings. They are also used where high driving torques are encountered, or where chips resulting from thread-cutting screws are undesirable.

Self-drilling tapping screws have points that drill their own holes. No other drilling or punching is needed, but these screws must be driven by a power screwdriver. Once the self-drilling screw pierces the metal, it forms or cuts threads the same way as standard tapping screws.

Special tapping screws

Typical specials include self-captive tapping screws and double-thread combinations. Self-captive screws combine coarse-pitch starting threads with finer pitch farther along the screw shank. Initially, the coarse threads cut the hole, but then the fine threads retap the hole and change the thread pitch. Attempts to back the screw out cause the coarse thread to interfere with the fine threads; consequently, the screw is held captive.

Double-thread screws combine a left-hand thread near the screw head and a right-hand thread over the rest of the shank. These screws can be driven only to the point where the left-hand threads start.

Another large group of special screws comes with preassembled washers. Some have a serrated face on the underside of the head which cuts into the assembly when tightened. This minimizes stripping caused by overdriving and increases holding power.

Sealing tapping screws, with preassembled washers or O-rings, can control leaks and crazing of enamel.

Setscrews

Setscrews are semipermanent fasteners that hold collars, pulleys, or gears on shafts. They are categorized by drive type and point style.

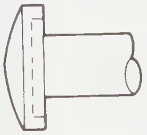
An important consideration in setscrew size selection is the holding power provided by the clamping action. Some additional resistance to rotation is contributed by point penetration. Cup-point and cone-point setscrews are used without a spotting hole. They penetrate the shaft deeper than oval-point or flat-point setscrews. Holding power is generally specified as the tangential force in pounds, since design considerations may cause different

SCREW HEAD STYLES

Head configurations depend on the driving equipment used (such as a screwdriver or socket wrench), type of joint load, and desired external appearance. Head styles shown can be used for both bolts and screws but are typically identified with the fastener category called "machine screw" or "cap screw."

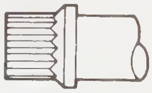
BINDING

This head is commonly used in electrical connections because the undercut prevents fraying of stranded wire.



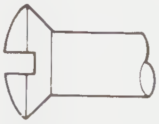
12-POINT

Twelve-sided head is normally used on aircraft-grade fasteners. Its multiple sides allow for a very sure grip and high torque during assembly.



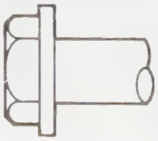
OVAL

This head has characteristics similar to a flat head but is sometimes preferred because of its neat appearance.



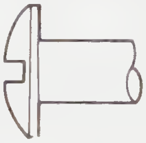
WASHER

Also called flanged head, this configuration eliminates a separate assembly step when a washer is required, increases the bearing areas of the head, and protects the material finish during assembly.



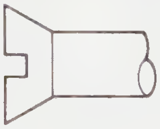
TRUSS

Head covers a large area. It is used where extra holding power is needed, holes are oversize, or material is soft.



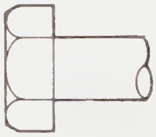
FLAT

Available with various head angles, the fastener centers well and provides a flush surface.



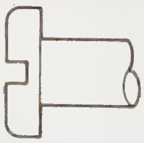
HEX

This has the same advantages as bolts of the same head style.



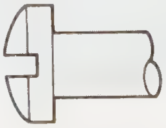
PAN

Head combines the qualities of truss, binding, and round heads.



FILLISTER

Deep slot and small head allow a high torque to be applied during assembly.



YARDLEY

SHARP-SERT INSERTS

PAT PEND.

Easy installation in plastics, particle board and wood

This versatile insert adapts to several methods of installation. Slightly curved hooks lock into material providing exceptional resistance to pull-out. Specially designed to secure against torque. Threaded area stays clean and chip free. Precision engineered. Available from stock in brass, in threaded sizes 2 - 56 to ¼ - 20.

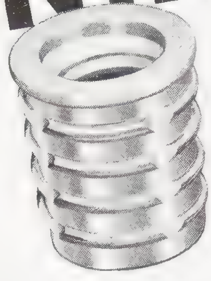
YARDLEY PRODUCTS CORP

10 WEST COLLEGE AVE • P.O. BOX 357 • YARDLEY • PA 19068
Phone: 215-493-2723
Fax: 215-493-6796

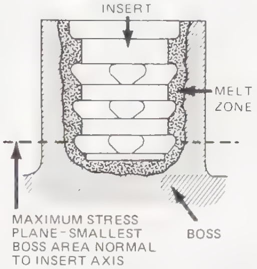
Circle 313

YARDLEY INTRO-SERT

THREADED METAL INSERTS FOR ULTRASONIC INSTALLATION



INTRO-SERTS. . .
- Reduce moulding cycle time
- Reduce mould construction cost
- Resist rotation pull-out
- Permit automated high volume production
- Rounded annular ribs reduce stress concentration which causes residual cracking


INSERT
MELT ZONE
MAXIMUM STRESS PLANE - SMALLEST BOSS AREA NORMAL TO INSERT AXIS
BOSS

YARDLEY INTRO-SERTS® give strong fastening threads for plastics. They are designed for high speed, low cost, ultrasonic installation in thermoplastics, in pre-drilled or pre-moulded holes. Insertion with a thermal tool is also practical. INTRO-SERTS are available in brass, aluminum and stainless steel, in thread sizes from 2-56 to 1/4-20.

Write or Phone for Free Samples and Information.

10 WEST COLLEGE AVENUE • PO BOX 357 • YARDLEY • PA 19068

YARDLEY PRODUCTS CORP

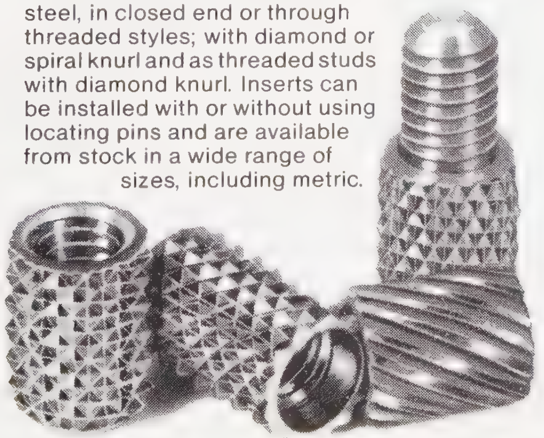
Phone: 215-493-2723 Fax: 215-493-6796

Circle 314

YARDLEY STANDARDIZED THREADED INSERTS

. . . For Molding into Plastics, Rubber and Ceramics

Yardley inserts are an economical means of providing a permanent, precision thread in molded or cast parts. Standardized inserts are available in brass, aluminum and stainless steel, in closed end or through threaded styles; with diamond or spiral knurl and as threaded studs with diamond knurl. Inserts can be installed with or without using locating pins and are available from stock in a wide range of sizes, including metric.



FOR FREE SAMPLES OR A COMPLETE CATALOG
Phone: 215-493-2723 Fax: 215-493-6796

YARDLEY PRODUCTS CORP A PREDCO COMPANY

10 W. COLLEGE AVE. • PO BOX 357 • YARDLEY • PA 19068

Circle 315

Lock Into Yardley® Inserts ...for Easy Installation and Great Holding Power

PAT.

TRISERT® Self-Tapping Insert

Three external flutes give full cutting action for plastic or soft metals. Can be installed from either end. Available in Brass, Steel and Stainless Steel. Sizes: 2-56 to 1/4-20.

PAT.

TRISERT® Coarse Threaded Self-Tapping Insert

Simplified installation and reduced installation torque. Efficient for weak or brittle plastics. Available in Brass. Sizes: 2-56 to 1/4-20.

PAT.

FIBER-SERT® Self-Tapping Insert

Great holding power and gives a permanent thread in wood, particle board and foamed plastics. Available in Brass. Sizes: 4-40 to 3/8-16.

For FREE samples & literature, call or write:
Phone: 215-493-2723 Fax: 215-493-6796
10 WEST COLLEGE AVENUE • PO BOX 357 • YARDLEY • PA 19068

YARDLEY PRODUCTS CORP
A PREDCO COMPANY

Circle 316

sizes of shafts to be used with a particular size of setscrew.

Setscrew selection is based on the fact that setscrew diameter should be equal to roughly one-half shaft diameter. This rule often gives satisfactory results, but its usefulness may be limited. Manufacturers' data, or data supplied by standard texts give more reliable results.

Seating torque: Torsional holding power is almost directly proportional to the seating torque of cup, flat, and oval-point setscrews.

Point style: Setscrew point penetration contributes as much as 15% to the total holding power. When the cone-point setscrew is used, it requires the greatest installation torque because of its deeper penetration. Oval point, which has the smallest contact area, yields the smallest increase in holding power.

Relative hardness: Hardness becomes a significant factor when there is less than 10 Rockwell C scale points difference between setscrew point and shafting. Lack of point penetration reduces holding power.

Flatted shafting: About 6% more torsional holding power can be expected when a screw seats on a flat surface. Flatting, however, does little to prevent the 0.01-in. relative movement usually considered as a criterion of failure. Axial holding power is the same.

Length of thread engagement: The length of thread engagement does not have a noticeable effect on axial and torsional holding power, provided there is sufficient engagement to prevent thread stripping during tightening. In general, the minimum recommended length of engagement is 1 to 1.5 times the major diameter of the setscrew for threading in brass, cast iron, and aluminum; and 0.75 to 1 times the diameter for use in steel and other materials of comparable hardness.

The lengths of engagement specified are for full threads engaged, not overall screw length.

Thread type: A negligible difference exists in the performance of coarse and fine threads of the same class of fit.

Drive type: The shape of the screw head has an effect on the seating torque that can be attained because it determines how much torque can be transmitted to the screw. Less torque can be transmitted through a slotted setscrew than a socket head setscrew. Therefore, holding power of the slotted screw is about 45% less.

Square-head setscrews can be tightened with a wrench until the screw fails. Recommended seating torques for square heads are about twice that for the socket setscrews, giving a proportional increase in holding power.

Number of setscrews: Two setscrews give more holding power than one, but not necessarily twice as much. Holding power is approximately doubled when the second screw is installed in an axial line with the first, but is only about 30% greater when the screws are diametrically opposed. Where design dictates that the two screws be installed on the same circumferential line, displacement of 60% is recommended as the best compromise between maximum holding power and minimum metal between tapped holes. This displacement gives 1.75 times the holding power of one screw.

Torque force: The compressive force developed at the point depends on lubrication, finish, and material.

Plating and lubrication: Most unplated setscrews are used with a thin film of rust-preventive oil. For added corrosion protection, setscrews can be plated with cadmium or zinc. An increase in the holding power for the same tightening torque results when

FASTEN WITH FIBERGLASS

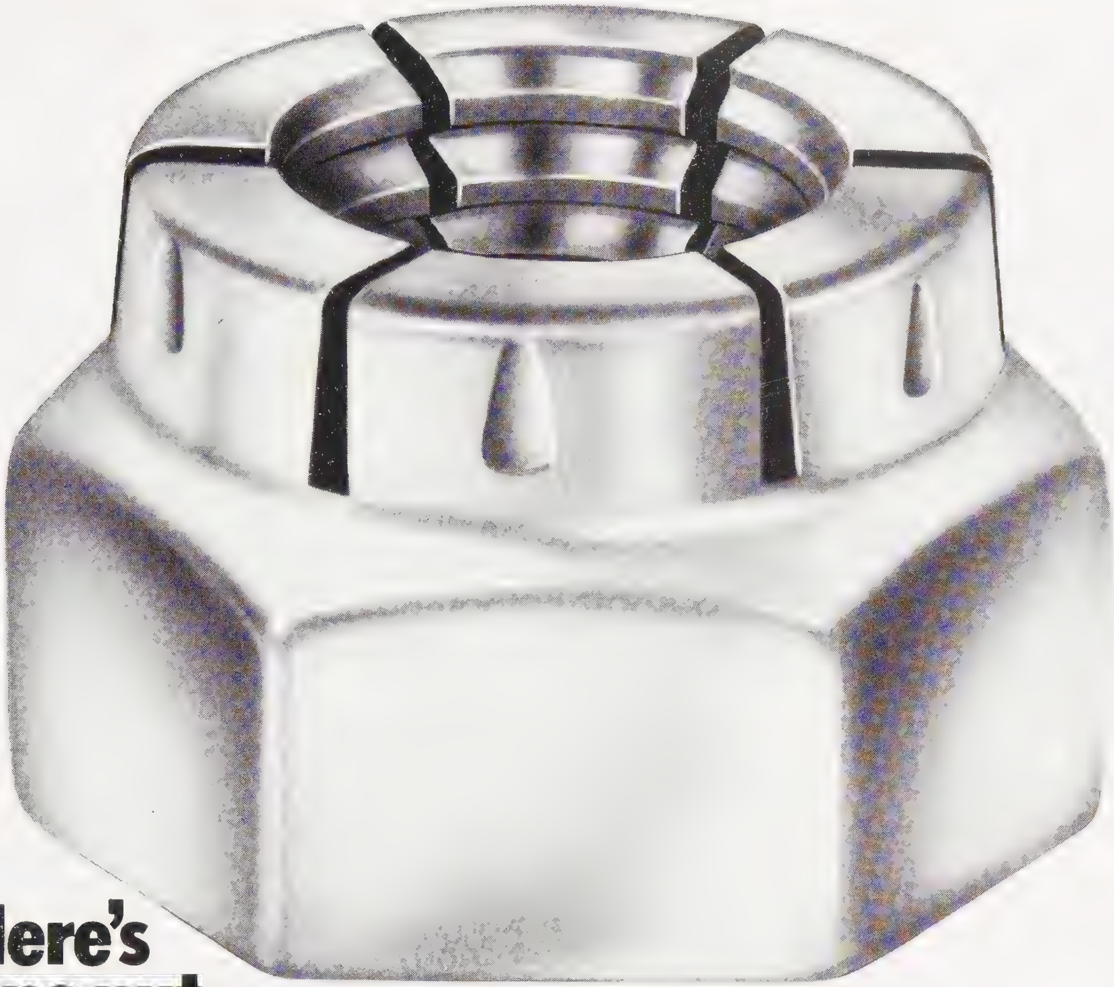
FIBREBOLT® fiberglass studs and nuts — the answer when you need a fastener that is:

- Corrosion resistant
- Low thermal conductivity
- Non-metallic
- Non-conductive
- Lightweight
- Easy to fabricate
- Available in 3/8″, 1/2″, 5/8″, 3/4″ and 1″

FIBRE BOLT®
Fiberglass Studs & Nuts

MMFG
MORRISON MOLDED FIBER GLASS COMPANY
P.O. Box 580 • 400 Commonwealth Avenue
Bristol, Virginia 24203-0580
(703)645-8000 • FAX (703)645-8132

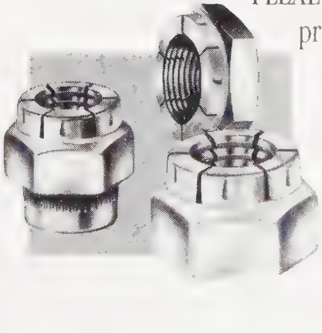
Circle 317



Here's one nut you'll never find running around loose.

Impact, shock, vibration.. none will budge a FLEXLOC® self-locking nut. This nut locks — and stays locked. Forget about wiring, jam nuts, lockwashers, cotter pins, and compounds. With all-metal FLEXLOC, the lock is built in. There's nothing to deteriorate under heat, dryness, or moisture.

FLEXLOC — the simplest, fastest, surest way to keep your product together. And they are reusable. For maximum strength, use FLEXLOC Full Height; for space and weight savings, Thin Height; for assembling thin-section materials, FLEXLOC Clinch Nuts. Your local FLEXLOC distributor has full stocks for immediate delivery. For more information, contact FLEXLOC Product Line Manager, SPS Technologies, Aerospace Products Division, Jenkintown, PA 19046, 215-572-3000.



SPS TECHNOLOGIES

Aerospace Products Division

Circle 318

the screw is plated or used with a suitable thread lubricant. However, the addition of these lubricants to the screw can reduce resistance to loosening.

Setscrews and keyways: When a setscrew is used in combination with a key, the screw diameter should be equal to the width of the key. In this combination, the setscrew holds the parts in an axial direction only. Torsional load on the parts is carried by the key.

The key should be tight fitting so that no motion is transmitted to the screw. Under high reversing or alternating loads, a poorly fitted key will cause the screw to back out and lose its clamping force.

Locking devices

Externally threaded fasteners with locking devices use the same techniques as locknuts. Prevailing-torque locking screws employ distorted threads, interference fits, inserts, or a chemical adhesive coating. Free-spinning locking screws and bolts have a locking feature incorporated into the head, or an additive on the threads.

Studs

Studs require a two-part assembly operation, but offer several advantages. They eliminate deviations from perfect squareness in an assembly. The ability of a nut to "float" and adjust on the nut end threads is an advantage of using the stud over the bolt or screw. The thicker the cover plate, or the longer the tapped hole, the more important this becomes.

In assembling and reassembling heavy parts such as turbine casings and cylinder heads, studs can act as pilots. Also, in the automatic assembly of small, lightweight units, studs reduce assembly costs since they permit quick and easy "stack up" of gaskets or other different parts of a joint.

Studs reduce the need for the large hole clearance and close hole alignment required by a cap screw or bolt. During assembly, the runout, or eccentricity, of cap screws and bolts is doubled as the fastener is turned. Clearance holes accommodate the runout which may cause eccentric loading and bending stresses in the joint.

Studs with an interference-fit thread or proprietary-lock thread on the tap end provide a positive lock against turning and loosening. The lock facilitates assembly and disassembly of locknuts on studs and is particularly important where maintenance of prestress is required to combat fatigue failures.

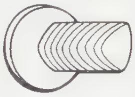
Studs applied with sealant prevent leakage of fluids through holes tapped in porous materials.

There are four basic stud types:

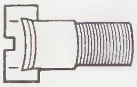
- Class 1 has an interference fit at one end and a free-running thread at the other. This is also called a gland or tap-end stud.
- Class 2 has free-running threads at both ends. This is also called a double-end stud.
- Class 3 is a three-bolt stud, which is used in high-temperature/pressure applications.
- Class 4 is used for general-purpose applications.

COMMON LOCKING SCREWS

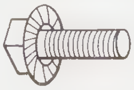
The locking action of thread deformation or deflection fasteners depends on metal-to-metal interference between the screw threads and mating threads.



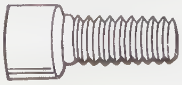
Undercut causes the head to act as a spring, absorbing shock and vibration load when the fastener is tightened.



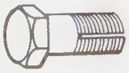
Flanged-head fastener has serrated or ratchetlike teeth which bite into the mating surface when the fastener is tightened. This type eliminates the need for a separate lockwasher.



Locking action of the thread comes from compressing a spring rib in the thread against the nonpressure flanks of the internal thread.



A pellet strip insert or a fused nylon patch projects beyond the thread crest. It is compressed when mating threads are engaged, creating the locking action.



Design notes

Bottoming or shouldering of studs should be avoided by driving them only to a predetermined depth. Bottoming or shouldering causes uneven standout and sets up undesirable radial compressive stresses which often become relieved during service operation, permitting the stud to loosen. Tapped holes in ferrous metals should be lubricated before driving studs.

Driving torque increases directly with length of engagement. For thin-wall applications, it may be desirable to use longer engagement rather than large-pitch-diameter interference to obtain desired driving torque.

For driving into ferrous material 160 Bhn and harder, the minimum length of engagement should be 1.25*D* (stud diameter); the maximum and minimum major diameter limits are reduced to permit plastic flow and to reduce and stabilize driving torque.

For driving into brass and ferrous materials with a hardness less than 160 Bhn, the minimum length of engagement should also be 1.25*D*. For driving into other nonferrous materials, it should be 2.5*D*.

For lengths of engagement of 1.25*D*, the external thread length should be 1.5*D*, with a tolerance of plus 2¼ pitches, minus zero. For lengths of engagement of 2.5*D*, the length of external thread and depth of full-form thread in the tapped hole should be set at 2.75*D*, with a tolerance of plus 2¼ pitches, minus zero.

Welded fasteners

The most common forms of welded fasteners are screws and nuts. Welded pins or unthreaded studs are also used, but as locating or bearing surfaces, rather than as fasteners. Welded fasteners are divided into two groups: resistance-welded threaded fasteners and arc-welded studs.

Resistance-welded fasteners

This fastener is an externally or internally threaded metal part designed to be fused permanently in place by standard production-welding equipment. Two methods of resistance welding are used:

Projection welding: Heat is localized through embossed or coined projections on the fastener. During the welding process, the projections coalesce with the part surface to form the weld. For best results, a press-type welder with electronic controls is usually recommended. This type of welder gives positive electrode alignment and equalized welding pressures.

Spot welding: The current is directed through the entire area under the electrode tip. Welding is usually performed by a spot welder. This type of welding equipment can satisfactorily weld a number of fastener designs.

Spot welding costs less than projection welding. However, the projection welder is more flexible and permits far greater latitude in design.

Design factors

The material most commonly used for weld fasteners is low-carbon steel such as 1010. Welded parts must be portable enough to be carried to the welder. Use of portable welding equipment with these types of fasteners is not recommended.

Production volume should be large enough to justify tooling costs. At least 1,000 parts are usually necessary to make the application of weld fasteners economically feasible.

Greatest use of weld fasteners is with sheet-metal parts from 0.030 to 0.125 in. thick. However, almost any fastener can be welded to any thickness of material as long as the materials are compatible, the welding operation is controlled, and the fastener itself is properly designed and not heat treated.

Arc-welded studs

In stud welding, the heat of an electric arc drawn between the fastener and the work melts a quantity of metal, after which the two heated parts are brought together under pressure. Welded fasteners must be made of a weldable material, and one end of the fastener must be designed for welding. Stud welding makes leakproof, pressure-tight connections and is adaptable to either automatic or semiautomatic operation. Automatic welds can be made at rates of up to 60 per minute. Electric arc and capacitor discharge are the two main stud-welding processes.

Electric-arc stud welding: In this semiautomatic electric-arc process, the heat for end welding the studs is from motor-generator or transformer-rectifier supplied dc current passing through an arc from the stud (electrode) to the plate (work). Weld cycle depends on stud diameter and may vary from 0.1 to 1 s.

A high-strength bond is obtained because the full cross-sectional area of the fastener or stud is fused to the base metal. Electric-arc stud welding is best used when the base plate is heavy enough to support the full strength of the welded fastener. However, lighter-gage materials are often arc welded. To avoid burn-through, the plate thickness should be at least one-fifteenth the weld-base diameter. To develop full fastener strength, basic plate thickness should be a minimum of one-third the weld-base diameter.

Capacitor-discharge stud welding: The second basic stud-welding process derives heat from an arc produced by a rapid discharge of capacitor-stored electrical energy, with pressure applied to the stud during or immediately following the electrical discharge. Like arc-stud welding, the heat for end welding of studs is developed by passage of current through an arc from the stud (electrode) to the plate (work).

A prime advantage of the capacitor-discharge system is its ability to weld studs to thin materials without great distortion, burn-through, or discoloration. Also, weld penetration is slight, so many dissimilar metals can be welded without metallurgical problems. Plates may be as thin as 0.016 in. for steel and 0.040 in. for aluminum.

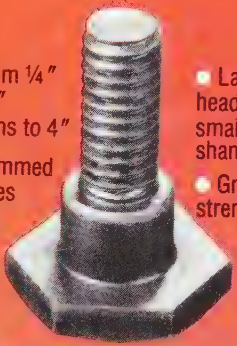
The three main capacitor-discharge stud-welding systems are: initial contact, initial gap, and drawn arc. These processes vary primarily in the manner of arc initiation. Gap welding is suited to the fabrication of heat-sensitive components. It is preferred for welding to nonferrous metals, especially to aluminum, and thin-gage metals, because it produces the least marking on the reverse side.

Applications

Fasteners smaller than 3/32 in. in diameter and bolts or unthreaded pins up to 1½ in. in diameter can be successfully welded. Fastener lengths vary from ½ to 40 in., depending upon end use. Fasteners may be made of mild steel, stainless steel, alloy steel, aluminum, brass, bronze, or magnesium.

Welded stud fasteners may be used to replace studs normally secured by drilling and tapping, arc welding, resistance welding, or brazing. The studs may be placed, where required, without regard to clearances behind the plate, and may be secured to expose surfaces after other assembly operations have been completed. The base metal must be weldable. Straight low-carbon steels

SPECIAL FASTENERS & PARTS from ANCHOR BOLT & SCREW



- From ¼″ to ½″ lengths to 4″
- Trimmed shapes
- Large heads, small shanks
- Greater strength
- Most metals: Ferrous, non-ferrous, stainless copper, monel, brass, bronze

Save assembly time, lower costs with special, multiple-blow cold headed parts from Anchor Bolt & Screw.

Reduce lead time on specials and virtually eliminate secondaries while increasing your ability to specify parts with extreme size differences: large heads, small shanks, trimmed shapes and more.

Uninterrupted flow of material in cold headed parts means greater strength, and parts formed on our multi-station parts former promise cost savings due to lower scrap rate.

Take advantage of ANCHOR's cold heading experience. Tap our skills now and profit from our knowledge.

Call Anchor today,
Toll-Free 1-800-ABS-IS-4U
(227-4748)

for samples, quantity prices and technical details.

Anchor: Quality At Every Turn

ANCHOR

©ANCHOR BOLT & SCREW CO 1990

ANCHOR BOLT & SCREW CO.
2001 N. Cornell Ave. Melrose Park, IL 60160
FAX: 708/343-7965

Circle 319

or austenitic (300 Series) stainless steels, except free-machining grades, produce good weld results with normal techniques. Other steel alloys can be welded, but heat treatment may be required to develop full weld strength. Many aluminum, brass, and copper alloys can also be welded. Weld quality with special materials may have to be determined through testing of prototype samples.

The most common fasteners used in electric-arc welding are made from low-carbon steels, with a minimum tensile strength of 60,000 psi and a minimum yield strength of 50,000 psi. Special high-strength fasteners, comparable in strength to SAE grade 5 bolts, are also available. Capacitor-discharge fasteners are generally made from C-1008 to C-1010 steels in the annealed condition. Tensile strengths are 40,000 to 50,000 psi. Austenitic stainless steel, magnesium-aluminum, silicon-aluminum, and other nonferrous fasteners are made most commonly from materials in the as-rolled condition.

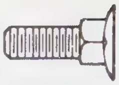
Fasteners for capacitor-discharge welding are most effectively used on flat or nearly flat surfaces. Since point contact is not needed for drawn-arc capacitor-discharge welding, fasteners can be welded to round or contoured surfaces. Electric-arc stud welding is adaptable to round or angle surfaces, since it depends on the ferrule for the formation of a relatively large pool of molten metal. The ferrule must be made to fit the contour in question.

Weld fasteners should be considered when:

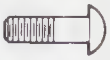
- Assembly requires any resistance welding of parts, sections, or braces. A fastener can often be welded in place along with the other parts to speed up production and assembly.
- Fasteners must be mounted in a location where wrenching or assembly operations would be difficult or impossible with conventional fasteners.
- Assembly requires a threaded section of a sheet-metal part or plate member. Welding a nut in place to serve as a thread anchor is often more convenient, less costly, and faster than forming and tapping a hole.
- Hidden fasteners are required in blind locations. Weld fasteners, either screws or nuts, can be readily attached to the enclosed side of a sheet-metal or plate section.
- Loosening of a fastener under vibration or shock is a critical problem.
- Permanent fastener attachment is required to avoid loose parts that might fall into equipment or get lost in assembly.
- A hermetically sealed fastener is

TYPICAL STANDARD BOLTS

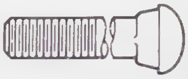
Elevator: Large-diameter flat-head bolt provides a nearly flush surface and large bearing area for use in softer materials. Square neck prevents rotation.



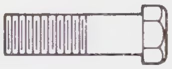
Round: This bolt presents a smooth external appearance and is tightened by torquing the mated nut.



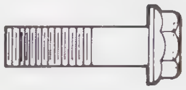
Track: A bolt designed specifically for use with railroad tracks, this version has an elliptical head to prevent rotation.



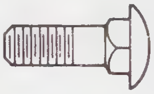
Hex: The most common standard fastener, it is supplied in three basic strength grades and in shank diameters ranging from ¼ to 4 in. The hex head design offers greater strength and ease of torque input than the square head.



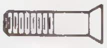
Flanged: Head gives a large bearing area and often eliminates the need for a separate washer.



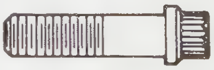
Carriage: These are normally made with a round head for an attractive external appearance, with ribs or flats on the shank to prevent turning when the bolt is tightened. Some versions require a prepunched square hole; others are pressed into place.



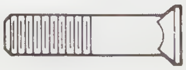
Countersunk: For flush mounting of assemblies, it is also called a stove bolt when supplied with a machine screw.



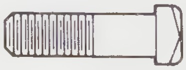
Aircraft: This term is used for many fasteners, but officially it is any bolt which conforms to DoD military standards.



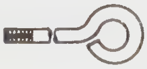
Plow: Usually made for flush mounting, this bolt has a square countersunk head, sometimes including a key to prevent rotation.



Square: This bolt is supplied in two strength grades and in sizes ranging from ¼ to 1½ in.



Bent: This is a threaded rod with an end formed to meet special requirements such as an eye or right-angle bend.



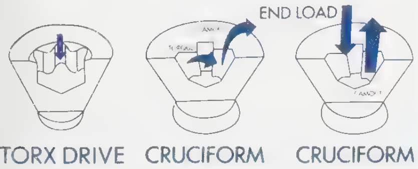
Turn fastener assembly
problems into a thing of the past!

he TORX® Drive System--because downtime just isn't acceptable

Everyone's experienced the
oblems--reamed recesses, broken
ts, worker fatigue, poor torque
ansfer. However, the **TORX Drive**
ystem is specifically designed to
vercome these problems.

he TORX Drive System:

- Virtually eliminates camout to reduce tool slippage and potential damage to the fastener and surrounding surfaces.
- Requires little or no end load to reduce worker fatigue and muscular stress caused by fastening.

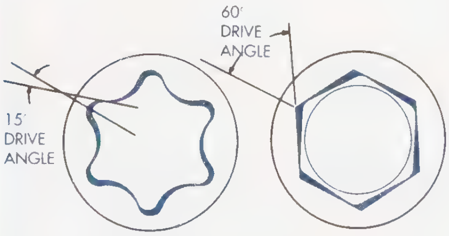


- Provides faster tool engagement to make it ideal for automated driving equipment.
- Offers more efficient torque transfer to ensure available torque is used to develop clamp load.

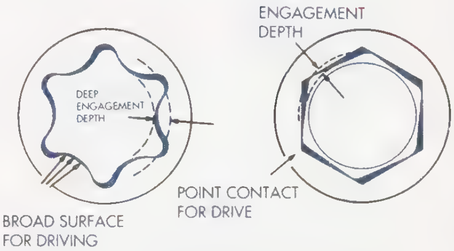
Why is the TORX Drive System better?

Only the TORX Drive was specifically designed to overcome the many problems associated with fastener driving.

It features:



- A 15° drive angle to closely simulate the optimum torque transmission angle found in gears.
- Straight, vertical side walls so no camout forces are created to push the driver up and out of the fastener. This also means the need for end load is greatly reduced.



- A broad contact surface and deep lobes spread the driving forces over a larger area for more efficient torque transfer and reduced tool wear.
- A hex-lobular design to eliminate the points of stress that round off corners and cause damage to the fastener and drive tool.
- Chamfers on the fastener and drive tool allow quick and efficient engagement.

Since the **TORX Drive System** can significantly reduce many of your assembly line problems, isn't it time to make the switch?

For more information on the Authentic TORX Drive System, call us at **1-800-544-6117.**

CAMCAR TEXTRON
Camcar Division of Textron Inc.

600 Eighteenth Avenue
Rockford, IL 61104-5181

X ® is a registered trademark of Camcar Division of Textron Inc.

TORX®

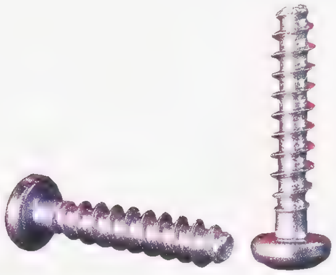
Circle 59 For Applications Assistance

What is the PT Screw for Thermoplastics?

PT Screws: Solutions by Design

Camcar Textron's PT Screws mean higher productivity and lower overall costs, with these added benefits:

- Allows thinner boss & wall designs
- Maximizes clamp load retention
- Offers high resistance to relaxation
- Reduces radial stress *(hoop stress)*
- Offers increased pull-out strength
- Minimizes vibration loosening
- Reduces boss cracking
- Allows reusability
- Lowers installation torqu



Offers Cost Savings

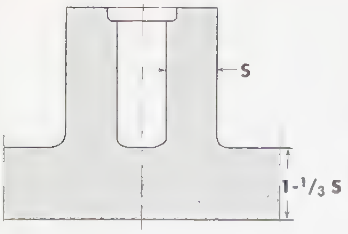
Only the PT thread-forming screw offers you the ability to reduce your material usage and molding cycle times to provide you with tremendous cost savings opportunities. Also, the PT screw's unique design allows you to eliminate tapping operations, costly inserts, adhesives and other supplemental locking devices.

The PT screw is specifically designed for thermoplastics, such as acetal, acrylic, styrene, polyethylene, polypropylene, nylon and polycarbonate.

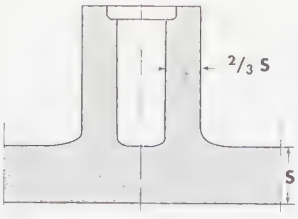
Allows Thinner Boss & Wall Designs

When using the PT screw, you can design thinner bosses, which allows you to reduce the thickness of your application's base. This will reduce your overall costs through decreased material usage and molding cycle times.

The PT screw can offer this benefit because it has a unique 30° thread profile, which generates less radial force on the boss diameter to reduce hoop stress.



Conventionally designed boss



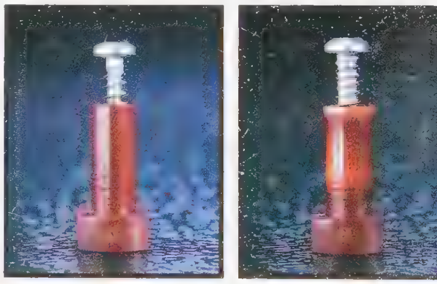
PT screw designed boss

Note: If boss wall thickness is greater than 66% of base, sink marks may form in the base. S = Base thickness

Reduces Radial Stress

Radial stress on the screw boss is reduced when using the P screw because of the unique thread profile. When compare to the conventional 60° thread profile, the PT screw's 30° thread profile generates half the radial force, to reduce hoop stress, without sacrificing thread engagement.

Also, a core recess at the minor diameter of the thread provides space for improved material flow during thread forming. This allows material to flow unrestricted into the thread root and reduce relaxation tendencies.



A plastic boss with a PT screw (left) shows reduced radial stress and boss damage

A plastic boss with a 60° thread form (right) shows radial stress and boss damage.

Maintains Clamp Load Over Time

Misalignment and the detachment of parts which produce squeaks and rattles, can be reduced with the PT screw. When material displaces to relieve itself from applied stres clamp load loss will often occur. The PT screw's 8° helix angle resists vibration loosening while maintaining a high load-carrying capability over time.

Resists Relaxation and Loosening

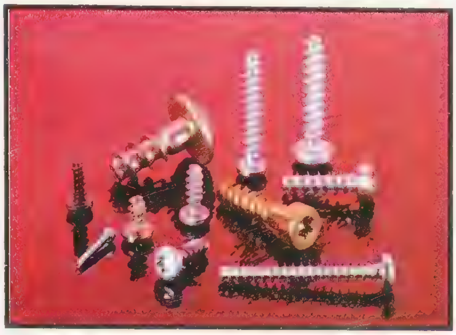
The increased contact area of the PT screw's thread profile in the engagement material provides greater resistance to relaxation. This also allows the PT screw to be used in repeat assembly operations.

Lowers Installation Torque

The thread design of the PT screw allows lower installatio torque, so the difference between drive torque and failure torque is higher, to reduce the potential for assembly failure. Also, this reduces the tendency of the plastic material to melt.

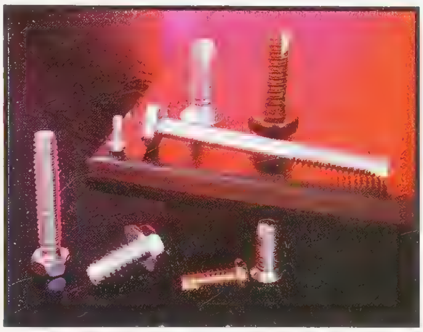
Circle 61 For Applications Assistance

esign Variations



ne PT screw for thermoplas-
cs is available in a wide array
styles and sizes to meet the
pecific needs of your applica-
ons. This design flexibility
lows you to take advantage
the cost saving benefits of
ne PT screw throughout your
perations.

DURO-PT Screws



The Duro-PT thread-forming screw offers low drive torques and high break-loose torques in light alloys, die-castings and engineering-grade plastics. A special profile at the minor diameter improves material flow during thread forming. Also, the Duro-PT screw features a 4° helix angle for greater pull-out strength and resistance to vibration loosening.

For thermosetting plastics, the Duro-PT screw is available with a shank slot. The specially designed shank slot moves material from the boss I.D. to the bottom of the boss. An improved flank design produces fewer chips and requires less drive torque.

Design Assistance

Good design is a prerequisite
f a secure joint. In order to
nsure you are achieving the
roven benefits of the PT
crew, our Applications
pecialists are available to
ssist you in proper fastener
nd boss design.

lease contact the Applica-
ons Specialists at our RHP Division for design assistance or informa-
on on technical seminars.

Size Ranges

M1.5 to M10 in Diameter
Up to 127 mm (5") under head

Head Styles

Pan
Flat
Round Washer
Hex
Hex Washer
Oval
Fillister
Button Head
Specials

Drive Systems

TORX® Drive
Hex
Phillips
Slotted
TORXstem® Drive
Indented Hex
Pozidriv®
Others

The Authentic TORX Drive System is recommended for use with the PT screw. The TORX Drive is designed to facilitate high torque transfer, especially when forming threads.

Specials

Shoulder Screws
Double End Studs
Others as required
Sems
Collar Studs

Rockford Headed Products

CAMCAR TEXTRON
Camcar Division of Textron Inc.

4814 American Road
Rockford, IL 61109-2661
PH: 815-874-6900
FX: 815-874-6912

Circle 63 For Applications Assistance
Circle 64 For More Information

RX®, TORXSTEM® and Solutions® are registered trademarks of Camcar Textron. PT® is registered trademark of EJOT Eberhard Jaeger GmbH. Pozidriv® is a registered trademark of Phillips Screw Co.

L0492-237 Printed in USA.

© Camcar Textron 1992

ON THE ASSEMBLY LINE...

THE TORX® DRIVE SYSTEM OVERCOMES THE LIMITATIONS OF PHILLIPS DRIVE.

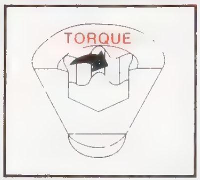
On the assembly line, the Phillips drive system is prone to reamed recesses, poor torque transfer, damaged drive bits and worker fatigue. However, the TORX Drive System is specifically designed to overcome the inherent limitations of Phillips, and similarly designed fasteners and tools.

THE TORX DRIVE SYSTEM:

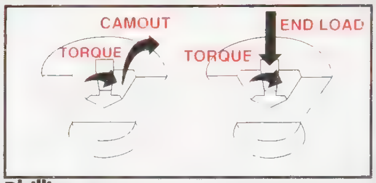
- **REDUCES FASTENER DAMAGE**
  Since camout is virtually eliminated with the TORX Drive System, tool slippage and potential damage to the fastener and surrounding surfaces is reduced.
- **PROVIDES EFFICIENT TORQUE TRANSFER**
  A 15° drive angle allows the efficient transfer of torque, to ensure the joint is being properly tightened.
- **PROLONGS TOOL LIFE**
  Camout forces often cause damage to the driving element. Because TORX Drive reduces camout forces, tool life is increased.
- **REDUCES WORKER FATIGUE**
  To overcome camout, additional operator end load is required, causing worker fatigue and muscular stress. TORX Drive reduces the need for end load, to reduce worker fatigue complaints.

Authentic TORX Drive products are available worldwide.

WHY IS THE TORX DRIVE SYSTEM BETTER?



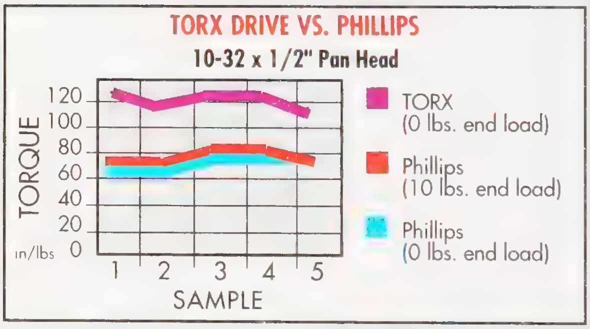
TORX (Fig.1)



Phillips (Fig.2) (Fig.3)

(Fig.1) TORX Drive features straight, vertical side walls so no camout forces are created to push the driver up and out of the recess.

(Fig.2) Phillips drive has inclined side walls, which deflect torque upwards, causing camout. To overcome camout, end load **(Fig.3)** is required. However, even when end load is added, the Phillips drive still can not match the performance of the TORX DRIVE SYSTEM



Above: The TORX fastener averaged a 220% increase in torque capability over a Phillips fastener. Even with 10 pounds of end load added to the Phillips fastener, TORX Drive still averaged a 184% increase in torque capability over the Phillips fastener.

If the problems of the Phillips drive system have plagued your assembly line, isn't it time you made the switch to the TORX DRIVE SYSTEM. For more information on the Authentic TORX Drive System, call us at **1-800-544-6117.**

Circle 65 For Applications Assistance
Circle 66 For More Information

CAMCAR TEXTRON
Camcar Division of Textron Inc

600 18th Avenue
Rockford, Illinois 61104
FAX: 815-961-5345

TORX® is a registered trademark of Camcar Textron

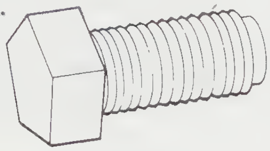
TORX®

"TAMPERPROOF" FASTENERS

Although almost all fasteners can, in some cases, be considered theft resistant, several types of threaded fasteners are specifically designed to be nonremovable once inserted, or to require special tools for removal.

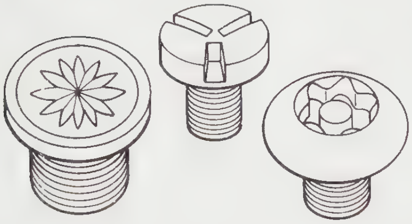
5-SIDED

Five-sided head requires special wrench.



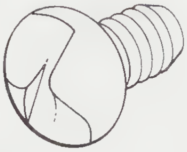
PROPRIETARY HEADS

Drive tools are usually available only from the fastener manufacturer.



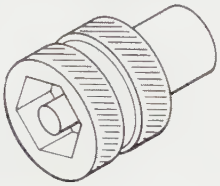
ONE WAY

One-way head is designed so that there is no bearing surface for the drive tool (a conventional screwdriver) in the reverse direction.



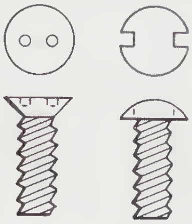
CAP SCREW

Cap screw has a plug added so that a conventional socket wrench cannot be used.



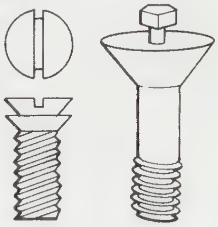
SPANNER

Spanner head does not have conventional drive slot. A modified screwdriver must be used as the drive tool.



BREAK-AWAY HEADS

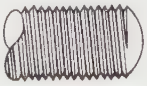
Break-away screw has a double head. When the fastener is seated, extra torque is applied to shear off the drive head, leaving the second head, which has no drive area, flush with the surface.



STANDARD POINTS

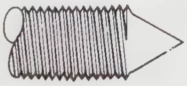
OVAL

This point is used when frequent adjustment is necessary or for seating against angular surfaces. In some applications, shaft is spotted to receive the point. It has the lowest axial or torsional holding power.



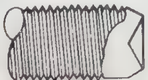
CONE

Used for permanent location of parts, it develops greatest axial and torsional holding power when bearing against material of Rockwell C 15 hardness or greater. It is usually spotted in a hole to half its length.



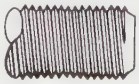
CUP

These are most widely used where the point's cutting-in action is not objectionable. Heat-treated screws of Rockwell C 45 hardness or greater can be used on shafts with surface hardness up to Rockwell C 35 without deforming the part.



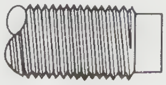
FLAT

These are used when frequent resetting of a machine part is required, and are particularly suited for use against hardened-steel shafts. They can also be used as adjusting screws for fine linear adjustments. A flat is usually ground on the shaft for better point contact. This point is preferred where walls are thin or threaded member is a soft metal.



HALF DOG

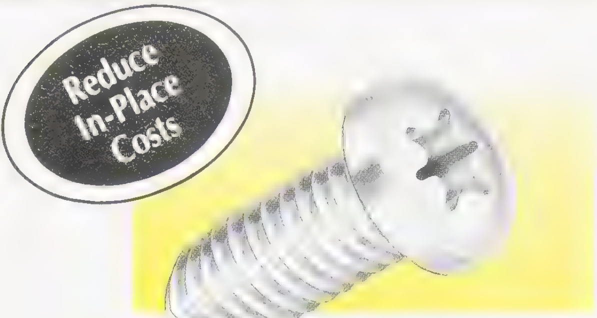
Normally applied where permanent location of one part in relation to another is desired, it is spotted in a shaft hole. Drilled hole must match the point diameter to prevent side play. This point is recommended for use with hardened members and on hollow tubing, provided some locking device holds the screw in place.



required. Use of sealing-type weld fasteners can eliminate the need for separate sealing elements.

Where clearance conditions or part shape indicate a need for special welding electrodes, consider reversing the fastener assembly. That is, if a weld screw with a conventional nut has been specified, try changing over to a weld nut and a conventional screw.

Through-hole fasteners eliminate the need for locating templates, jigs, and fixtures. Where through-hole screws or nuts are used, the diameter of the hole in which the fastener is located should be at least 0.010 to 0.015 in. larger than the fastener's major diameter. This clearance is generally considered optimum for handling ease and weld-spatter elimination. A smaller clearance will hinder positioning of the fastener. A larger clearance may lead to misalignment and faulty welds. ■



Cut In-Place Fastener Costs!

ES-FORM®

High Performance Thread Forming Screw

FROM ESKAY

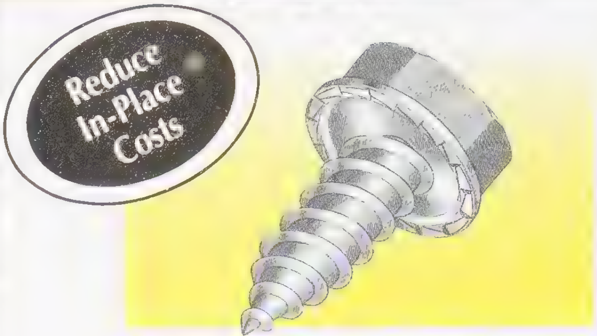
Es-Form® is a registered trademark of Eskay Screw Corp.

- Elimination of tapping
- Elimination of nuts and lock washers
- Greater thread contact
- Greater vibration resistance
- Near perfect thread mating
- Competitive pricing

FOR INFORMATION, CALL OR WRITE:

Eskay
ESKAY IS STAINLESS
321 Foster Avenue, Wood Dale, Illinois 60191
Phone: (708) 595-6250 Fax: (708) 595-0336

Circle 320



Cut In-Place Fastener Costs!

ES-GRIP®

For Light Gauge Sheet Metal

FROM ESKAY

Es-Grip® is a registered trademark of Eskay Screw Corp.

- Greater strip out resistance
- Reduced scrap & rework
- Reduced operator fatigue
- Recessed head creates locking effect
- Higher drive to strip torque rat
- Competitive pricing

FOR INFORMATION, CALL OR WRITE:

Eskay
ESKAY IS STAINLESS
321 Foster Avenue, Wood Dale, Illinois 60191
Phone: (708) 595-6250 Fax: (708) 595-0336

Circle 321

Cut In-Place Fastener Costs!

TRI-PLASK®

Thread Forming Screw for Plastic

FROM ESKAY

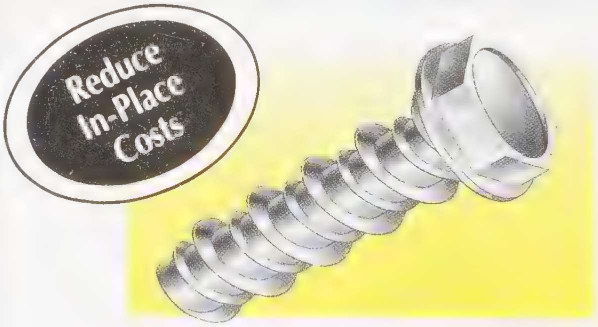
Tri-Plask® is a registered trademark of Eskay Screw Corp.

- Greater holding power
- Greater vibration resistance
- Near perfect thread mating
- Reduces Boss Failure
- Greater Drive to Strip Out Torque
- Competitive pricing

FOR INFORMATION, CALL OR WRITE:

Eskay
ESKAY IS STAINLESS
321 Foster Avenue, Wood Dale, Illinois 60191
Phone: (708) 595-6250 Fax: (708) 595-0336

Circle 322



Cut In-Place Fastener Costs!

PLASK H/L®

Double Lead Screw for Plastic

FROM ESKAY

Plask H/L® is a registered trademark of Eskay Screw Corp.

- Unique high & low thread design
- Greater thread engagement
- Reduced boss failure
- Greater driving to strip torque
- Greater holding power
- Competitive pricing

FOR INFORMATION, CALL OR WRITE:

Eskay
ESKAY IS STAINLESS
321 Foster Avenue, Wood Dale, Illinois 60191
Phone: (708) 595-6250 Fax: (708) 595-0336

Circle 323

Nonthreaded fasteners

Nonthreaded fasteners are often simple designs that solve a wide range of fastening problems.

Rivets and pins, two inexpensive alternatives to threaded fasteners, can be used in automated assembly. However, pins are used where ease of disassembly is desired, while disassembling riveted parts usually destroys the rivets.

There are two basic families of rivets: tubular and blind. The main difference between them is that blind rivets require access to only one side of the assembly for installation.

Tubular rivets

Economic considerations, not performance requirements, determine the optimum diameter for tubular rivets. Rivet shank length, however, is fixed by the amount of the rivet material needed for clinching and the total material thickness.

To minimize initial costs, a rivet of standard shank diameter, length increment, and tolerances should be specified. Some high-volume rivet sizes are particularly inexpensive. For example, 0.125 in. is by far the most popular nominal shank diameter. A 0.125-in. carbon-steel rivet can cost less than rivets with shank diameters from 0.085 to 0.089 in. Unless limited by load-carrying requirements, the 0.125-in. rivet should be used.

Larger rivet-shank diameters are more efficiently fed in automatic assembly operations, and low-carbon steel and brass rivets are most easily handled in riveters. Extremely soft, low-density rivet materials can cause feeding and clinching difficulties.

Rivet length-to-diameter ratio should be limited to a maximum of 6:1 when possible, so standard barrel hoppers can be used. Higher length-to-diameter ratios may require special feeding devices, such as continuous hopper drives or vibratory feeders. For rivets above the 6:1 ratio or with long shanks, the head diameter should be about twice the shank diameter for efficient automatic handling.

Steel, aluminum, or brass are considered standard cold-heading materials. Almost any soft grade of aluminum can be cold formed into rivets. Carbon steels from grades AISI 1006 through 1035, 1108, and 1109 provide good strength at reasonable cost.

The location of the rivet in the assembled product influences both joint strength and clinching requirements, with edge distance and pitch distance being the important dimensions.

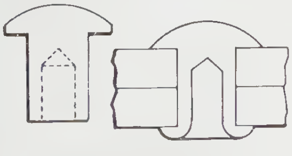
Blind rivets

Parts can be fastened by a rivet if flat parallel surfaces exist for both the rivet clinch and head and there is adequate space for the rivet driver during clinching.

When a blind rivet is set, a self-contained mechanical feature expands the rivet's shank, securing the parts being

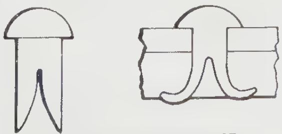
TYPES OF TUBULAR RIVETS

Rivet shanks have hole depths greater than 1.12 times shank diameter. They can punch their own holes in fabric, some plastic sheet, and other soft materials. Shear strength is less than that of semitubular rivets.



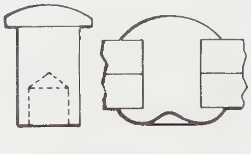
FULL TUBULAR

Also called split rivets, these fasteners have bodies that are punched or sawed to produce prongs that make their own holes through fiber, wood, plastic, or metal.



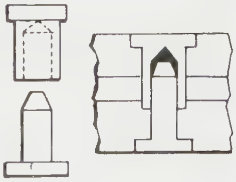
BIFURCATED

The most widely used rivet, this fastener has a straight or tapered hole in its end with a depth that never exceeds 1.12 times shank diameter. When properly specified and set, the hole depth is just enough to form the clinch. Strength of semitubular rivets in shear or compression is comparable to solid rivets.



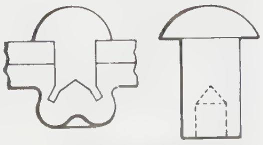
SEMITUBULAR

Male and female members form an interference fit when pressed together. Heads can be produced to close tolerances; therefore, these are commonly used when appearance from both sides of the work must be uniform and heads must be flush to prevent accumulation of dirt or waste. Compression rivets can be used in wood, brittle plastics, or other materials with little danger of splitting during setting.



COMPRESSION

Closely resembling semitubular rivets, the metal-piercing rivet has greater column strength. These rivets can pierce a total sandwich of about 0.15 in. Fastened material is limited in hardness to around RB 50.



METAL PIERCING

SMALLEY STEEL RING COMPANY Wheeling, IL 60090 708-537-7600

Free Copy
ask for
Smalley Catalog
No. WS-89

Spirawave®
Wave Springs
Engineering and Parts Catalog

Stock Sizes
- Carbon steel and stainless steel
- ½″ to 16″
- 16 mm to 580 mm

Special Designs
- Design information and applications included
- No tooling costs

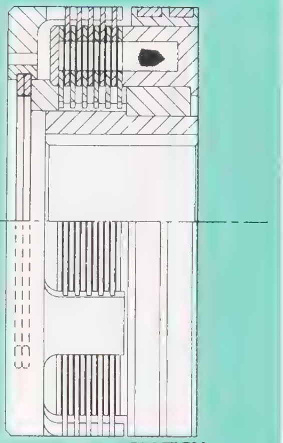
Call to Order: **Smalley**
Steel Ring Company
385 Gilman Ave.
Wheeling, IL 60090
708-537-7600

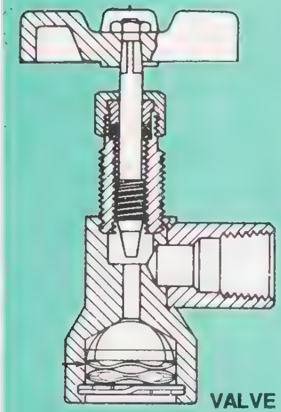
ing and Spring Applications

1 Strict Groove Depth Requirements

Problem The chief engineer at a clutch manufacturer was revising one of his present designs. He needed a retaining ring for a new clutch assembly, a fairly typical internal housing application, that called for a ring with an outside diameter of 2.500 in. However, the engineer had a problem with the groove depth. The maximum depth he could permit was .050 in. to maintain strength in the casting. But he also wanted to maintain adequate thrust capacity. Realizing that a greater groove depth provides greater thrust capacity and a higher safety margin, the groove diameter was specified at 2.600/2.59 in. The engineer needed a non-standard retaining ring.

Solution The design engineer considered two types of retaining rings: a Smalley Spiral Retaining Ring and a conventional die-stamped retaining ring. He specified the **Smalley Spiral Retaining Ring** because he was able to get two different pre-production samples for testing and evaluation quickly and economically. Because of the spiral process, the special, non-catalog sizes were produced to the correct diameter without traditional tooling costs. The samples were tested and the better of the two was ordered in larger quantities. Besides minimizing development costs, Smalley delivered the total quantity in less than 3 weeks.


CLUTCH


VALVE

2 Premature Failure with Spot-Weld Wave Washers

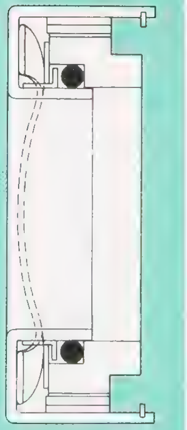
Problem A ball valve manufacturer had a compression spring application with a working height of .500 in. and a stroke of .350 in. compressing the wave spring to a final working height of .150 in. There were load specifications at both working heights. The manufacturer used an assembly of individual wave washers spot welded together to form a series-stack configuration. He had several problems with this design. The first was that the spot welded springs required extra time and fixturing for the welding operation. The welded area became annealed (soft) due to the heat of welding and premature failure always occurred at these points. Either the material fatigued or the spot welds themselves separated after too many cycles.

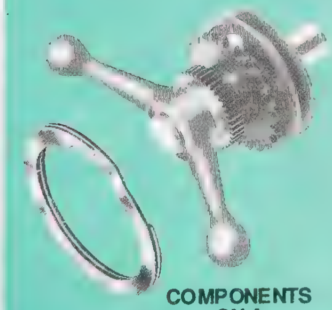
Solution The **Smalley Crest-to-Crest Spirawave** compression spring eliminated the high cost of spot welding, assembly time and early failure. The manufacturer learned that the Spirawave was edgewound from a length of flat wire into one continuous piece. As a single unit, like a conventional round wire spring, it held its series configuration naturally, achieving the same load/deflection properties as the spot-welded assembly without the weld problems. There were no annealed areas within the spring and fatigue cycling was no longer a problem.

3 Exact Spring Force Unknown

Problem A face seal manufacturer was using a stamped wave washer to spring load the seal's carbon face against a sealing surface. Each new face seal design required a new spring design, a costly and time consuming task. As is often the case in new designs, the exact spring force was unknown and several prototypes had to be produced. The force had to be held to very rigid specifications to provide proper sealing and wear characteristics of the seal.

Solution The manufacturer called on Smalley. He found out that **Smalley Wave Springs** did not require special dies or tooling for new designs because they were edgewound instead of die stamped. Because of this, several prototypes were produced with various physical differences such as spring rate, force, number of waves and material cross-section. Prototype seals were tested economically and springs shipped within two weeks. Besides solving this problem, the manufacturer found additional advantages with Smalley Wave Springs. He saw that the spring load was controllable to within ± 10% of nominal value as opposed to a stamped spring at ± 20% to ± 30%. This repeatability reduced inspection procedures and timely in-house reworking of the seals. Also, the Smalley spring, due to its inherent split design, could pilot tightly in the seal bore eliminating undesirable rattling associated with the stamped wave washer.


SEAL


COMPONENTS ON A SHAFT

4 Machined Shoulder or Retaining Ring?

Problem The chief design engineer with a conveyor company had a common design situation with a shaft that had several components to be retained in position. He could use either a machined shoulder or a retaining ring. He eliminated the machined shoulder because the shaft would have to be machined from oversized stock which was not economical in higher volumes, and there was considerable expense involved to machine 90% of each shaft length. On the other hand, a die stamped retaining ring had a gap between the removal ears and the chief engineer worried that the part abutting the ring would work its way into the open areas.

Solution The shaft design problem was solved by a **Smalley Spiral Retaining Ring**. The two-turn spiral ring provided a complete 360 degree retaining surface similar to a machined shoulder, leaving no spaces for trouble. In addition, the assembly was to be field serviceable and the spiral ring was removable with any standard screwdriver.

Circle 324

SMALLEY STEEL RING COMPANY Wheeling, IL 60090 708-537-7600

Free Copy ask for Smalley Catalog No. RR-90

Smalley® Spiral Retaining Rings

Engineering and Parts Catalog

STOCK SIZES

- Carbon and Stainless Steel
- 1/2" to 16"
- 12mm to 280mm

SPECIAL DESIGNS

- Design Information
- Applications
- No Tooling Costs

Smalley
Steel Ring Company
Edgewound-Coiled Retaining Rings and Wave Springs

Smalley
Steel Ring Company

385 Gilman Ave. • Wheeling, IL 60090

Ordering

Smalley Retaining Rings

Smalley manufactures and distributes retaining rings in both medium/high volume quantities (OEM) and low/prototype quantities (Quickship), factory direct.

To place your order or check pricing, contact:

OEM Sales		Quick-SHIP
(Medium/High Quantities)	OR	(Low/Prototype Quantities)
708-537-7600		800-537-7600
3 Weeks	DELIVERY	48 Hours
OEM Prices (Ask for Discount Schedule)	PRICE	$10.00 Minimum per part $25.00 Minimum per order
Standards 1/2" to 15" 12mm to 280mm **Specials** 5/16" to 84" 8mm to 2200mm	RING SIZES	**Standards** 1/2" to 15" 12mm to 280mm
Carbon 1070-1090, 302, 316,17-7 Stainless, inconel, coppers and other alloys.	MATERIALS	Carbon 1070-1090, 302 Stainless

INTERCHANGE LISTING

SMALLEY® SPIRAL RETAINING RINGS

SMALLEY	SPIROLOX	MILITARY MIL-R-27426	AEROSPACE AS 3219	METRIC AEROSPACE MA 4035	WALDES TRUARC	EATON	INDUSTRIAL RETAINING RING	ANDERTON
[illegible]	UR	—	—	—				
[illegible]	US	—	-	—				
[illegible]	RR	TYPE B CLASS 1	AS 3217	—				
[illegible]	RS	TYPE A CLASS 1	AS 3218	—				
[illegible]	RRT	—	-	—	—	NAN	-	
[illegible]	RST	—	—	—	—	XAN		
[illegible]	RRN	TYPE B CLASS 2	AS 3215	—	N5000 5008	I N	3000 4000	1300
[illegible]	RSN	TYPE A CLASS 2	AS 3216	—	5100 5108	E N	3100 4100	1400
[illegible]	—	—	—	MA 4017	—	—	-	
[illegible]	—	—	—	MA 4016	—	—	-	

GROOVE INTERCHANGE ONLY
Use a Smalley Retaining Ring to fit into the same groove of these stamped Retaining Rings

Manufactured in U.S.A. 01-90

Circle 325

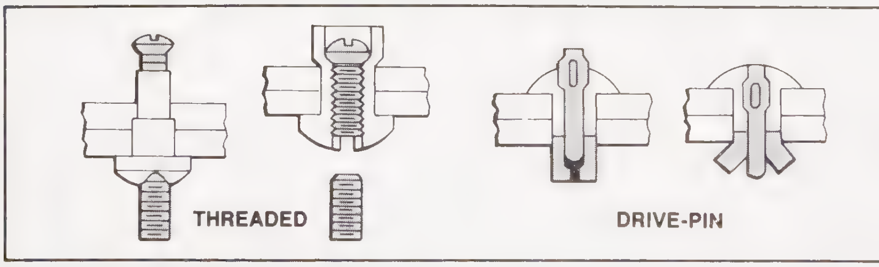
AUTOMATED ASSEMBLY WITH TUBULAR RIVETS

Rivets are often the most economic choice when considering automatic assembly. Here are the major considerations when using tubular rivets:

- Shape is the primary consideration when selecting rivets for automatic assembly because some shapes feed more easily than others. Rivets shorter than one body diameter or longer than seven or eight body diameters are often difficult to feed.
- Head diameters too large or too small relative to body diameter can also cause tracking problems. Vibratory feeders can alleviate these problems somewhat, but, in general, rivets with head diameters of about 1.7 to 2 times body diameter and head thicknesses of 25 to 30% of body diameter feed best.
- A 6:1 length/diameter ratio allows use of standard rotary hoppers on the riveting machine. Longer rivets require special drum, blade, and vibratory hoppers in conjunction with long-stroke riveting machines.
- Riveting can be automated to almost any degree to fit virtually all high-volume production requirements. Fairly complicated products like small appliances can be assembled at rates of 600 to 2,000/h, with a single factory turning out 32,000 assemblies/h.
- Rivet-setting equipment can be partially or totally automated. Riveters range from light to heavy-duty 50-ton units and can be mechanically, pneumatically, or hydraulically driven. A variety of feed systems and rivet holders can be selected to fit the specified degree of automation.

Experience has shown that hard automation systems are more economical for riveting operations. Surprisingly, hard automation does not sacrifice flexibility because, in practice, quick-change fixtures, stops, modules, versatile programs, etc., complement each other to build a high degree of versatility into the system. This allows identical, but different-sized components to be assembled with the same equipment.

TYPES OF BLIND RIVETS



These two-part rivets consist of a body and a mandrel preassembled within the body. The mandrel is gripped and pulled axially after the rivet is inserted into the joint, so that its head upsets the blind end of the rivet body to form a set rivet.

Three subclassifications of pull-mandrel blind rivets are: pull through, break, and nonbreak. In the pull-through type, the mandrel is pulled completely through the rivet body, leaving a hollow rivet. A plug can be inserted to seal the hole.

A break-type mandrel is pulled into or against the rivet body and then broken off, leaving part of the mandrel in the body as a plug. The retained mandrel section increases the shear strength of the installed rivet if it remains in the shear plane. The rivet may have a completely closed blind end to prevent liquid or gas leakage after installation.

Nonbreak types include pull mandrel, drive pin, and threaded. In the pull-mandrel type, the mandrel is pulled into or against the rivet body, but does not break. The mandrel is removed in a subsequent operation. In the drive-pin type, a drive pin from the rivet is hammered into the body to flare out the blind side of the rivet. Threaded blind rivets consist of an internally threaded rivet and an externally threaded mandrel which is torqued or pulled with a special tool. This expands the walls of the rivet body to form a blind head.

joined. These rivets are most often installed in joints which are only accessible from one side.

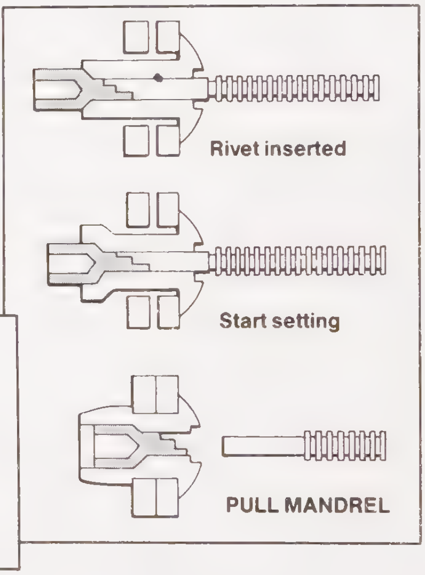
Blind rivets are also used to simplify assembly, improve appearance, or decrease cost where both sides of the joint are accessible. Blind riveting offers portability — the riveting can be brought to the work. This is valuable for large assemblies.

Blind rivets should be used where:

- Fastener removal is not necessary for maintenance.
- High vibration exists.
- A temporary fastener is needed.
- Uniform clamping is desirable.
- Repair fasteners for field use by untrained personnel are needed.

Blind rivets are classified as pull mandrel, threaded, or drive pin, according to the methods by which they are set.

Physical characteristics: Blind rivets have three different core styles, retaining different amounts of the pin or mandrel after they are set. A filled rivet contains enough of the mandrel or pin so that the break point of the mandrel or the end of the pin is approximately flush with the top of the rivet head. This style provides high shear strength. A semifilled rivet contains a short length of the mandrel in its core. A hollow rivet has a completely empty core and is advantageous when light weight is important. It is also useful in electronic applications because it eliminates the possibility of loose mandrels disrupting circuits, and leaves a grommeted hole for ventilation or to pass wires through.



Diameter is based on the measurement of a blind rivet's shank, usually in 0.03125-in. increments. Grip range is the range of material thickness that can be joined properly with a blind

If There's A Hole In Your Product . . .

When a hole in your product needs to be closed, filled or plugged, consider this simple, economical solution from Stimpson, maker of the world's largest variety of Hole Plugs.

Whether to plug a tube end, close a panel hole, an access hole, or to decorate your product, Stimpson can furnish the right Hole Plug to suit your requirements at a surprisingly low cost.

Stimpson Hole Plugs are available in a large variety of metals, platings, enameled and special finishes, complete with designs stamped to your specifications.

Standard, Tubing, Electrical Knockout and Special Hole Plugs . . . over 160 of them are illustrated in our latest Stimpson Hole Plug catalog complete with all necessary dimensions to help you choose the correct one for your application. Send for your free copy today.

Stimpson

900 SYLVAN AVE., BAYPORT, NY 11705-1097
(516) 472-2000 • FAX (516) 472-2425 • TX-ITT-497-2370

Circle 326

TIPS FOR DESIGNING WITH RIVETS

Semitubular and tubular rivets should not be used in tension, but their compression and shear strengths are on a par with solid rivets.

Long tubular and semitubular rivets may buckle in oversized holes.

If a joint will undergo torque load, use two rivets, rivets with serrations under the head, or an interlocking joint design.

If counterboring is necessary, do not forget clearance for the rivet-setting tool.

When joining compressible materials, use rivets with large-diameter heads and a star-set clinch or cap. For maximum strength, use washers or burrs with tubular and semitubular rivets.

Use washers to strengthen riveted joints in brittle material or to reinforce thin sections.

When joining thick and thin sections, the head should be against the thin section.

Allow space for the setting tool when positioning rivets near the edge of a section.

rivet of a given length. Manufacturers furnish specific recommendations. Sealing properties vary considerably, depending on the style of the blind end. If sealing is critical, it should always be checked under operating conditions.

Design considerations: Joint design factors that must be known include allowable tolerances of rivet length vs. assembly thickness, type and magnitude of loading, hole clearance, and joint configuration.

Power tools install most rivets efficiently. However, drive-pin rivets are most quickly installed with a hammer. Manual installation tools can be used efficiently with little or no training.

In-place costs of blind rivets are often lower than solid rivets or tapping screws because of low tooling investments, high installation speed, and requirement of just a single operator. Also, inventory can be reduced if one rivet with a large grip range is used for several joints of different thicknesses.

Blind-rivet joints are usually loaded in shear, which the rivets can support better than tensile loading. Rivets subject to vibration perform more efficiently if manufacturer-specified minimum hole clearance is maintained.

Material thickness requirements can be as thin as 0.020 in. with some rivets. If one component is of compressible material, rivets with extra-large head diameters should be used on that side of the application to uniformly distribute the load over a larger area.

Installation costs: Blind rivets cost slightly more than conventional tubular ones, but they allow faster installation and reduced assembly costs that can make up the initial price difference. Originally for fastening applications where only one side of the workpiece was accessible, these rivets are often used in other applications to reduce assembly time.

Break-stem blind rivets consist of a body and mandrel. To set the rivet, the placement tool engages the mandrel and provides an axial pull. This causes the mandrel head to upset the tail of the rivet, forming a blind head. When the mandrel reaches its designed tensile load, it breaks at a predetermined point on its shank. The portion in the tool is then discarded.

Cost savings provided by break-stem blind riveting are somewhat reduced because rivets usually are handled individually, and the broken mandrels must be removed from the work area. Broken mandrels sometimes are left in a workpiece, resulting in further production delays and associated costs. These disadvantages can be overcome by cartridge-fed blind-riveting systems. Such systems install packaged sets of rivets with a tool having a built-in permanent mandrel. Production rates for this system may be many times faster than those of break-stem systems, with a proportionate reduction in assembly costs.

Vacuum collection is another way to overcome the problem of broken mandrels. For example, one system uses pneumatic power to install rivets as well as to generate a vacuum that holds rivets in place before installation and vacuums away spent mandrels as the rivet is installed.

Drive-pin rivets also eliminate the broken-mandrel problem. The pin remains in this type of blind rivet, increasing its shear strength as well.

Rivet advantages: Some advantages of rivets include:

- Initial rivet cost, labor costs, and machine time to set the rivets in parts are lower than those of threaded fasteners. This is true because rivets are made in large volumes on high-speed heading machines with little scrap loss.
- Dissimilar materials, metallic or nonmetallic, of various thicknesses can be joined. Any material that can be cold worked provides a suitable rivet.
- Rivets can have a variety of finishes such as plating, parkerizing, or paint.
- Rivets can serve as fasteners, pivot shafts, spacers, electric contacts, stops, or inserts.
- Parts that are painted or have other finishes can be fastened by rivets.

On the negative side, tensile and fatigue strengths of rivets are lower than comparable-diameter bolts and machine screws with nuts, though tensile strength for ½-in.-diameter blind rivets can be over 2,300 lb. However, rivets are the least susceptible to vibration loosening. That is why aircraft manufacturers rely heavily on rivets. While riveted joints are weatherproof, they are not normally sealed against air or water under pressure. A sealing compound, rivet coating, or special washer may be used but at added cost.

Rivets produced in volume are not normally made with the same precision as screw-machine parts. Normal tolerances on major dimensions are 0.005 in., although closer shank-diameter tolerances can be held. Rivets should not be used where dimensional variation must be maintained as low as 0.001 in.

Semipermanent pins

Pins are typically used under primarily shear loading. They are separated into two groups: semipermanent and quick release.

These general design rules apply to all types of semipermanent pins:

- Avoid conditions where the direction of vibration parallels the pin axis.
- Keep the shear plane of the pin a minimum distance of one diameter from the pin end.
- Allow pins to protrude the length of the chamfer at each end for maximum locking effect in applications where engaged length is at a minimum and appearance is not critical.

Removal and installation of semipermanent pins require the application of pressure or the aid of tools. The two basic types of semipermanent pins are

How to put 75,000,000 springs and spring washers on the tip of your finger.

SPEC®

Stock Springs,
Spring Washers
and Retaining Rings

Associated Spring
Raymond
BARNES

Your new Associated Spring SPEC® catalog will put over 8,000 different product designs and the world's largest inventory of springs and spring washers right at the tip of your finger.

Stock solutions for prototype, development, maintenance, modeling and emergency needs. Thousands of designs for everything from bicycles to aircraft, machine maintenance to computers.

With over 75 million parts in inventory, chances are we have what you need in stock and ready for immediate shipping, usually within 24 hours. Our extensive distribution network includes nine shipping centers throughout North America to assure you get the spring you need when you need it.

We also put service at the tip of your finger. When you call our toll-free order hotline at **1-800-872-7732**, you get an immediate, knowledgeable response. And technical engineering experts are always available to assist with your design and problem-solving needs.

Your solution is as close as the tip of your finger. Call **1-800-872-7732** toll-free for your FREE copy of the new SPEC catalog. Because without the latest edition, you'll be missing out on more than 2,000 new designs and the industry's most comprehensive catalog ever!

Don't wait. We're ready to spring into action, now!

Associated
Spring
BARNES

©1991 Barnes Group Inc.

Circle 327

machine pins and radial-locking pins.

Machine pins are separated into four categories: dowel, taper, clevis, and cotter.

Hardened and ground dowel pins are standardized in nominal diameters ranging from 1/16 to ⅞ in. Standard pins are 0.0002 in. oversize on the nominal diameter; oversize pins are 0.001 in. oversize.

Standardized pin lengths vary with nominal diameter, ranging from a minimum of 3/16 in. (1/16-in. size) to a maximum of 5¼ in. (⅞-in. size).

Some dowel pins are threaded and tapered for use with a tapered sleeve. The threaded section allows the pin to be pulled from the sleeve, and a special sleeve puller removes the sleeve. This reusable dowel-and-sleeve combination can properly align holes as much as 0.001 in. oversize. It is said to speed machine-shop operations by eliminating knockout holes, eliminating the need to turn dies to remove dowels, and enabling machinists to remove and replace die sections while the die is in the press.

Taper pins have a taper of ½ in./ft measured on the diameter. Basic dimension is the diameter of the large end. Diameter d of the small end is given by $d = D - 0.02083\ L$ where D = diameter of the large end, in., and L = pin length, in.

The standardized series of numbered pin sizes ranges from No. 7/0 (0.0625-in. large end) to No. 10 (0.7060-in. large end).

Clevis pins have nominal diameters from 3/16 to 1 in. Corresponding shank lengths vary from 19/32 in. for 3/16-in. size to 2⅝ in. for 1-in. size. Standard material is steel, either soft or cyanide hardened to meet service conditions.

Cotter pins come in a number of point styles and have been standardized into 18 sizes with nominal diameters ranging from 1/32 to ¾ in. Available materials include mild steel, brass, bronze, stainless steel, and aluminum.

Grooved straight pins have a locking action provided by parallel, longitudinal grooves uniformly spaced around the pin surface. Rolled or pressed into solid pin stock, the grooves expand the effective pin diameter. When the pin is driven into a drilled hole slightly larger than the nominal pin diameter, elastic deformation of the raised groove edges produces a secure force-fit with the hole wall.

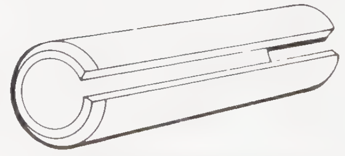
Standard groove-pin sizes cover a range of nominal diameters from 1/32 to ¼ in. in varying lengths from ⅛ to 4¼ in. Materials include cold-drawn steel, alloy steel, stainless steel, and copper alloys.

Low-carbon-steel groove pins have load capacity in single shear from 110 lb for a 3/64-in. size to 10,300 lb for a ¼-in. size. Higher shear strength may be obtained from heat-treated pins.

Locking force developed by a groove pin assembly is a function of pin diameter and effective length of engagement. Best results under average assembly conditions are obtained with holes drilled the same size as the nominal pin diameter. Undersize holes must be avoided. This practice can lead to deformation of the pin in assembly, damage to hole walls, and shearing off the raised groove edges, thus reducing holding action and preventing reuse of the pin.

When the part material is appreciably harder than that of the pin, chamfered or rounded hole edges should be specified to avoid shearing of the expanded pin section. Shearing may be avoided by using through or case-hardened pins. Hardness of the pin and the metal fastened should be equal.

Spring pins use the resilience of hollow cylinder walls to hold in place. The two main types are spiral-wrapped and slotted tubular pins. Both pin forms are made to controlled diameters greater than the holes into which they are pressed. Compressed when driven into the hole, the pins exert spring pressure against the hole wall along their entire engaged length to develop locking action.



SLOTTED TUBULAR PIN

Spiral-wrapped or coiled pins come in standard sizes that cover a range of nominal diameters from 1/32 to ¾ in., in lengths from ⅛ to 6 in. Metric diameters range from 0.8 to 20 mm. Standard materials are: 70/30 brass, copper alloy 25, heat-treated 1070 to 1095, carbon steel, stainless steel (302 and 402), and 6150 alloy steel.

Locking force of a spiral-wrapped pin is a function of length of engagement, pin diameter, and wall thickness. Three pins are available for light, medium, and heavy-duty applications.

Slotted tubular pins come in standard sizes from 1/16 to ¼ in. and lengths from ⅛ to 5¼ in. Standard materials are heat-treated carbon steel, corrosion-resistant steel, and beryllium-copper. Readily adaptable to manual assembly techniques, these pins offer a tough, resilient, self-locking fastener that can withstand high shock and vibration loads.

Spiral-wrapped pins have an advantage over slotted pins in automatic assembly because they cannot interlock during feeding. They may also resist vibration and absorb shock better than slotted pins because the coil design can flex after assembly, while the slotted version cannot flex after the gap is closed.

For maximum shear strength, the pin should be assembled so that the gap is in line with the direction of load and 180° away from the point of application. The maximum shear strength value provided by this orientation represents an increase of about 6% over the minimum value.

Quick-release pins

Mainly used for rapid manual assembly and disassembly, quick-release pins employ some form of mechanism to provide a locking action. They use a clearance fit in holes formed to nominal diameters and are divided into two major types — push-pull pins and positive-locking pins.

Push-pull pins are made with a solid or a hollow shank containing a detent assembly in the form of a locking lug, button, or ball which is backed up by some type of resilient core, plug, or spring.

These pins are made 0.002 to 0.004 in. undersize to fit any standard hole drilled to nominal-diameter dimensions. Pullout loads can be expected to decrease as looseness of fit increases. Hole edges should be deburred or slightly chamfered to ease assembly.

Primary function of these pins is to fasten parts under shear loading. Ideally, the load direction should be at right angles to the shank of the pin. Locking mechanisms are designed to provide secure retention against accidental disassembly. These pins are not recommended for loads in tension.

Positive-locking pins have a locking action that is usually independent of insertion and removal forces. These pins are also primarily suited for shear-load applications. However, some degree of tension loading can be tolerated without affecting the pin function.

Positive-locking pins are divided into three categories: heavy-duty cotter pins, single-acting pins, and double-acting pins.

Heavy-duty cotter pins employ a forged, high-carbon steel body to replace the conventional split-cotter construction. Locking action is provided by a tempered-steel snap ring mounted

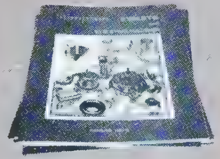
Design with Stimpson Eyelets in mind...

At STIMPSON, we realize that each eyeleting application presents its own problems and requirements. Whether it's a question of decor, dimension, tensile or sheer stress, STIMPSON Eyelets provide designers everywhere with substantial cost savings and design flexibility.

STIMPSON Eyelets are lightweight, durable, and easy to use, making them one of the most economical mechanical fasteners in use today.

STIMPSON'S full range of over 3,300 eyelet sizes and styles gives designers the flexibility needed to meet their new or changing design specifications.

For more complete design information, send today for your free copy of our latest Eyelet catalog, which illustrates our Standard and Specialty Eyelets along with our full line of automatic eyeleting machines.



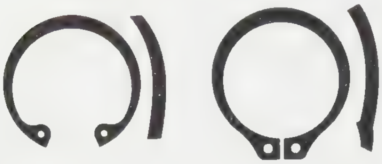
Stimpson Co. Inc.

900 SYLVAN AVE., BAYPORT, NY 11705-1097
(516) 472-2000 • FAX (516) 472-2425 • TX-ITT-497-2370

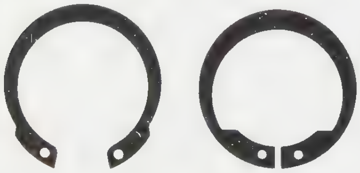
Circle 328

DESIGN CONSIDERATIONS FOR STAMPED RETAINING RINGS

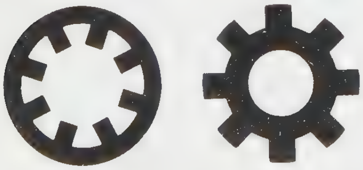
These rings offer springlike retention and eliminate of end play for applications on small-diameter shafts, bores, or housings. Except for the curved shape, they have the same characteristics as their flat-ring counterparts.



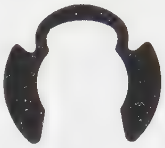
Rings are fitted into machined grooves. They are either internal for installation in housings and bores, or external for assembly on shafts. Once installed, they serve as shoulders for retaining parts.



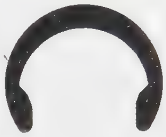
Prongs dig into the shaft when the ring is loaded on the other side. The prongs of the external push-on ring give when the ring is applied to a metal or plastic shaft. When a force is applied against the ring, the prongs lock it into position. The internal version of the ring functions similarly, except the prongs are positioned on the outside of the ring. This type is ideal for use in housings and bores.



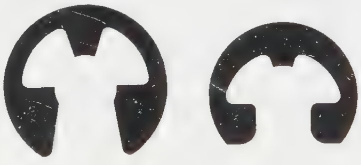
This ring offers extremely wide abutment against the retained part. Once assembled, the ring presses inwardly against the groove, resulting in stable installation.



The C retaining ring functions in small spaces, yet its tapered inner surface provides a tight, secure grip around the groove.

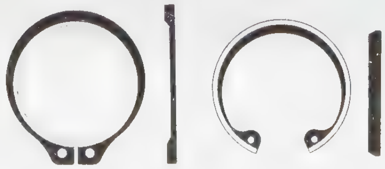


Large shoulder retention is the hallmark of the E-series retaining ring. It features three prongs which, when radially installed, contact the bottom of the groove. E-rings require a deeper groove but provide exceptional thrust loading when compared to fasteners of the same size and weight.

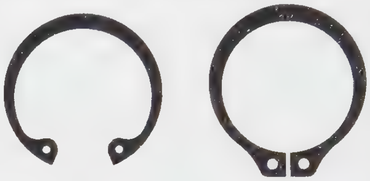


Reinforced E-rings can replace standard E-rings, permitting higher thrust loadings and increased effectiveness against rotational speeds. Applications in which the retained assembly is subject to heavy shocks and vibration are also best served by this ring.

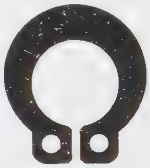
These rings are similar to their flat counterparts. The main difference is a 15° beveled edge which is complementary to the load-bearing groove wall. When end play occurs, the ring's spring action causes it to grip the groove more tightly. This results in effective end-play take-up and keeps the assembly intact.



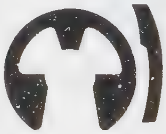
Inverted lugs allow for applications requiring greater clearance than those offered by the basic external and internal ring. Large section height is ideal for applications with curved abutting surfaces and large corner radii or chamfers.



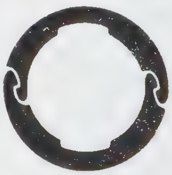
Tapered section of the ring causes extremely large frictional forces against an ungrooved shaft. This gripping power is exerted uniformly on the shaft, except where the gap occurs. As a result, assemblies can be retained without relying on a groove.



Resilient end-play take-up is achieved in an axial direction while the ring firmly grips the bottom of the groove.



This ring is produced in two halves. The ends interlock into a groove on a shaft and, once assembled, are dynamically balanced. As a result, they are particularly effective at retaining assemblies with extremely high rotational speeds.



on the head of the pin.

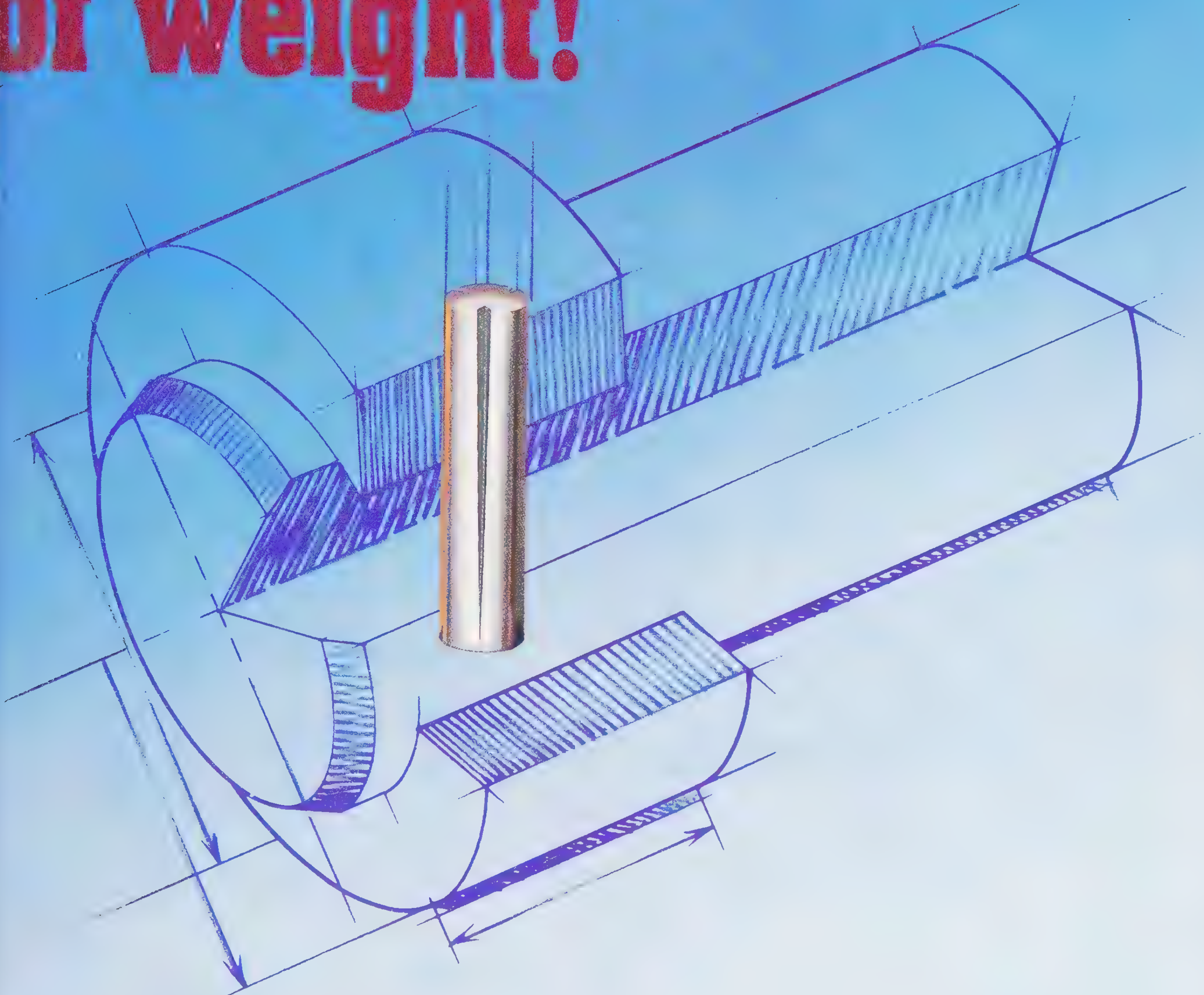
Single-acting pins have locking action controlled by a plunger-actuated locking mechanism. In the locked position, the locking element projects beyond the surface of the pin shank to provide a positive lock. When the plunger is moved by means of a button or lever assembly at one end of the pin, the locking element retracts. A number of head styles and release mechanisms have been developed for these pins.

Double-acting pins are a modification of single-action types, and have a bidirectional, spring-located plunger. Movement of the plunger in either direction releases the locking balls.

Retaining rings

Also known as snap rings, retaining rings provide a removable shoulder to locate, retain, or lock components on shafts or in bores and housings. They are usually made of spring steel and

This little pin carries a lot of weight!



"A lot can ride on a little." "Great things come in small packages." "It may be little, but it's mighty!"... never have such adages been more descriptive, or more true than when discussing today's industrial-use grooved fasteners, drive pins, keys and studs. **That's why Driv-Lok puts so much extra into the design, development and quality-controlled manufacture of their products.**

Typical examples of this Driv-Lok dedication to quality rests in the complete line of standard type, grooved pin designs... each one guaranteed to be manufactured cleaner and more precise.

Today, in all types of industries all across the nation, more engineers specify and more manufacturers use Driv-Lok grooved fasteners, spring pins, press fit drive pins, keys and studs in their products than any other brand.

For more information write **Driv-Lok, Inc., 1140 Park Ave., Sycamore, IL 60178,** or call **815-895-8161, FAX 815-895-6909**.

Driv-Lok pins carry a lot of weight in the industry... and on the job!

DRIV-LOK® INC.

have high shear strength and impact capacity. These rings can also be used to take up end play caused by accumulated tolerances or wear in the parts being retained. Three categories of rings are stamped, bent-wire, and spiral-wound retaining rings.

Stamped rings

Stamped retaining rings have a tapered radial width that decreases symmetrically from the center section to the free ends. Tapered construction permits the rings to remain circular when they are expanded for assembly over a shaft or contracted for insertion into a bore or housing. This constant circularity assures maximum contact surface with the bottom of the groove.

Stamped retaining rings are classified into three groups: axially assembled, radially assembled, and self-locking rings. Axially assembled rings slip over the ends of shafts or down into bores, while radially assembled rings have side openings and are snapped directly into grooves on a shaft.

Most axially assembled rings have holes in the lugs at the free ends for special pliers that expand or contract the rings for installation or removal. Radially assembled rings are installed with an applicator and removed with a screwdriver or other hand tool. Self-locking rings do not require grooves. They are available for assemblies in which the fastener need not absorb any sizable thrust, but instead serves mainly as a positioning or locking device.

Most stamped retaining rings are made of high-carbon spring steel with corrosion-inhibiting finishes such as phosphate coating, cadmium or zinc plating, and chemical-conversion coatings for special applications. Rings made of aluminum or beryllium copper are available for special assembly requirements, usually without any protective finish. Corrosion-resistant stainless-steel rings are also available.

Design considerations

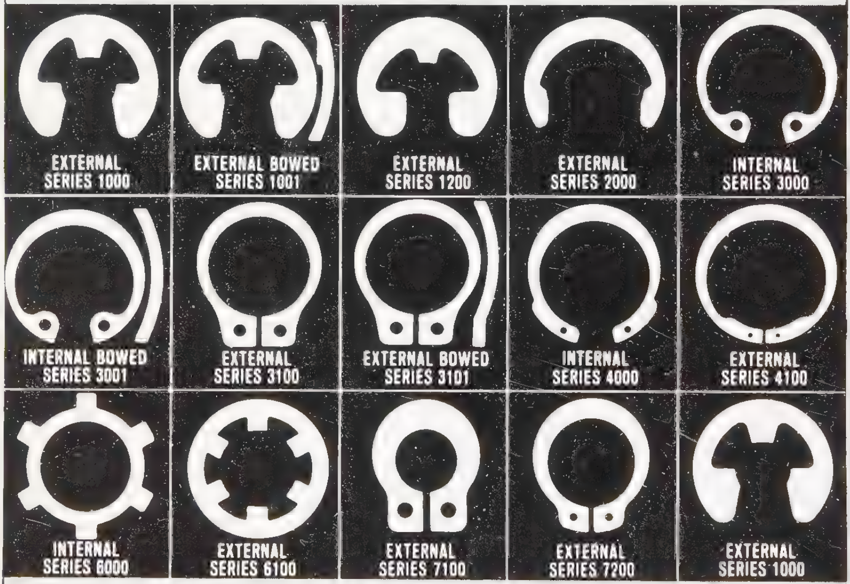
Standard ring sizes range from 0.040 to 10 in. in diameter, although rings as large as 40 in. in diameter have been made. Rings are also manufactured for metric shaft and bore diameters. Both ring and groove load capacities should be considered when selecting specific ring types; the lower of the two will be the limiting factor in the assembly. The ultimate thrust load to which a ring may be subjected depends upon the ring's shear resistance; ultimate groove thrust-load capacity depends on a factor of compressive resistance.

For optimum ring performance, the retained parts should have an abutting face that is straight with sharp corners. This enables loads to be transmitted as closely as possible to the groove wall. The thickness of the ring resists shearing and provides maximum uniform compression loading for the groove wall. If the abutting face is curved, and the resultant of the forces is transmitted to the ring at a distance from the shaft or bore circumference, a bending moment is created that will cause the ring to dish. The groove wall will not be loaded uniformly, reducing the ultimate thrust capacity.

Retaining-ring manufacturers specify maximum allowable corner radii and chamfers for each ring size, with corresponding static thrust capacities. If thrust capacities are insufficient for the assembly, a rigid, square-cornered, flat washer should be inserted between the ring and the retained part. The washer is mandatory if the assembly is subject to dynamic loading and the retained part has a corner radius or chamfer.

INDUSTRIAL RETAINING RINGS

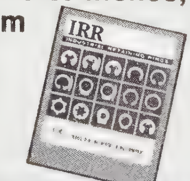
AVAILABLE FROM STOCK



INDUSTRIAL RETAINING RINGS are ready when you want them because INDUSTRIAL consistently manufactures and stocks quality-controlled retaining rings by the billions in all our standard types and sizes in carbon spring steel, stainless steel and beryllium copper.

INDUSTRIAL RETAINING RINGS save time and money by providing inexpensive shoulders on shafts and in housings, and by eliminating fastening devices that require costly machining and assembling. Available for shafts .04 to 8 inches and housings .25 to 8.25 inches, INDUSTRIAL RETAINING RINGS conform to government and industry standards.

Call or write for free samples, the IRR catalog, and the IRR distributor list.



IRR
The Ring Of Quality

INDUSTRIAL RETAINING RING CO.
Manufacturer of quality retaining rings since 1950
57 Cordier Street, Irvington, New Jersey 07111
Telephone: (201) 926-5000 • FAX: (201) 926-4699

Circle 330

When Quality and Savings Come First . . .
Think Stimpson C-E® Rivets.

C-E® Rivets are specially designed for light to medium riveting applications to give you up to 40% savings over conventional tubular riveting.

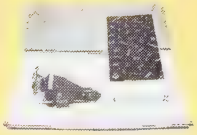
Furnished in three of the most popular shank diameters, in brass and steel with most plated and color enameled finishes. Also available with matching caps for extra strength and finished appearance.

Stimpson is prepared to give you the quality and savings needed for today's most common riveting applications.

C-E® Rivets teamed up with the "C-1" or No. 500 Machine, provide you with one of the most economical and versatile riveting Systems available today.

Why not submit your product or components to our Assembly Service experts for free analysis, and assembly? We will submit samples and attractive prices.

Send for your free copy of Stimpson's latest C-E® Rivet Brochure which illustrates our full line of C-E® Rivets and precision built automatic machines.



Stimpson
Co. Inc.

900 SYLVAN AVE., BAYPORT, NY 11705-1097
(516) 472-2000 • FAX (516) 472-2425 • TX-ITT-497-2370

Circle 331

GROOV-PIN

The name tells only half the story

Since 1926, we've developed broad lines of fasteners for manufacturers who need special engineered pins and inserts.

Call for literature or samples... Or Fax us your design application. We'll send the samples best suited to your need.

Fax: (201) 945-8998 for Free Samples

Tell us how we can help with your product or design:

- Your base material?
- Your end product?
- Size of pin/insert/hole?
- Pin/insert material?
- Test quantity?

Groov-Pin's broad line includes:

- Tap-Lok® Self-Tapping Inserts
- Form-Lok® Thread-Forming Inserts
- Push-in or Ultrasonic Inserts for Plastics
- Seal-Lok® Spark Plug Inserts
- Spring Pins
- Knurled Pins
- Drive Studs
- Riv-Sert® Blind Rivets
- Grooved Pins

GROOV-PIN CORP.

1125 Hendricks Causeway
Ridgefield, NJ 07657
(201) 945-6780 FAX: (201) 945-8998

Circle 332

Clearance depends on the type of ring used. A crescent ring, for example, has a substantially lower shoulder than an E-ring, and for many assemblies supplies a sufficiently large bearing surface. Rings with inverted lugs form a uniformly circular protruding shoulder and provide more clearance than basic internal and external types.

Edge margin is the shoulder between the outer groove wall and the end of the shaft or housing. Minimum is generally considered to be three times the ring's nominal groove depth.

Axial-type rings have generally higher rotational speed limits and present a neater appearance. Radial rings are usually easier to install and remove.

Axial play in the assembly can be compensated for by bowed rings where resilient end-play take-up is permissible. Beveled rings can be used for rigid take-up. Self-locking rings, which can be positioned at any point on a shaft or in a housing, can also compensate for accumulated tolerances.

Wire-formed rings

Split rings formed and cut from spring wire of uniform cross-sectional size and shape are known as wire-formed rings.

Rings are available in many cross-sectional shapes, but the most common have rectangular or round cross sections. Rectangular-section rings are made for internal or external applications. Round-section rings are for external use on shafts only and are used where the expected load is light.

Ring assembly and disassembly tools range from a screwdriver to automatic tools, depending on the application.

Carbon spring steel (SAE-1060) is the standard material used in retaining rings. In addition, a wide range of carbon steels (SAE-1010 to SAE-1095) are used, including pre-oil tempered and alloy steels. Hardnesses range from 43 to 53 Rockwell C, with tensile strengths from 200,000 to 280,000 psi. Other materials used are stainless steel, yellow brass, silicon or phosphor bronze, Inconel X, beryllium copper, aluminum, and K-Monel.

Design considerations

Wire-formed rings are available for shafts or housings in diameters from ⅛ to 30 in. The controlling factor in designing a wire-formed ring (other than size) is the amount of thrust the ring is to absorb. In most cases, retaining rings withstand greater shear loads than the groove material because of the strength of the hardened spring-steel ring section.

The controlling factor in size selection is thrust capacity of the ring. Wire-formed retaining rings, because of their configuration, usually do not fail in shear. Under an increasing load, the ring deflects and finally jumps out of the groove.

This type of failure can be reduced by increasing ring width (section height measured in plane or diameter). Wider rings have more resistance to expansion forces that would work the ring out of the groove.

Although rings can be made with almost any combination of section width and thickness, rectangular-section thicknesses are usually 2 to 5% of the shaft or bore diameter. Width of these sections varies from two to three times the thickness.

Ideally, the shaft and the retained part should have strength equal to or better than the ring. The groove should be square, concentric, and held to such dimensions that a close slip fit is provided with the sides of the ring. The bearing surface of the retained part should be perpendicular to the shaft axis with no corner radius.

If these conditions cannot be met in practice, the wire-section corner radius, mating-part radius, and tolerances should provide an adequate flat surface for the ring to bear against.

Shear strength of the groove material can be increased by increasing the distance from the edge of the groove to the end of the shaft or by increasing the strength of the groove material.

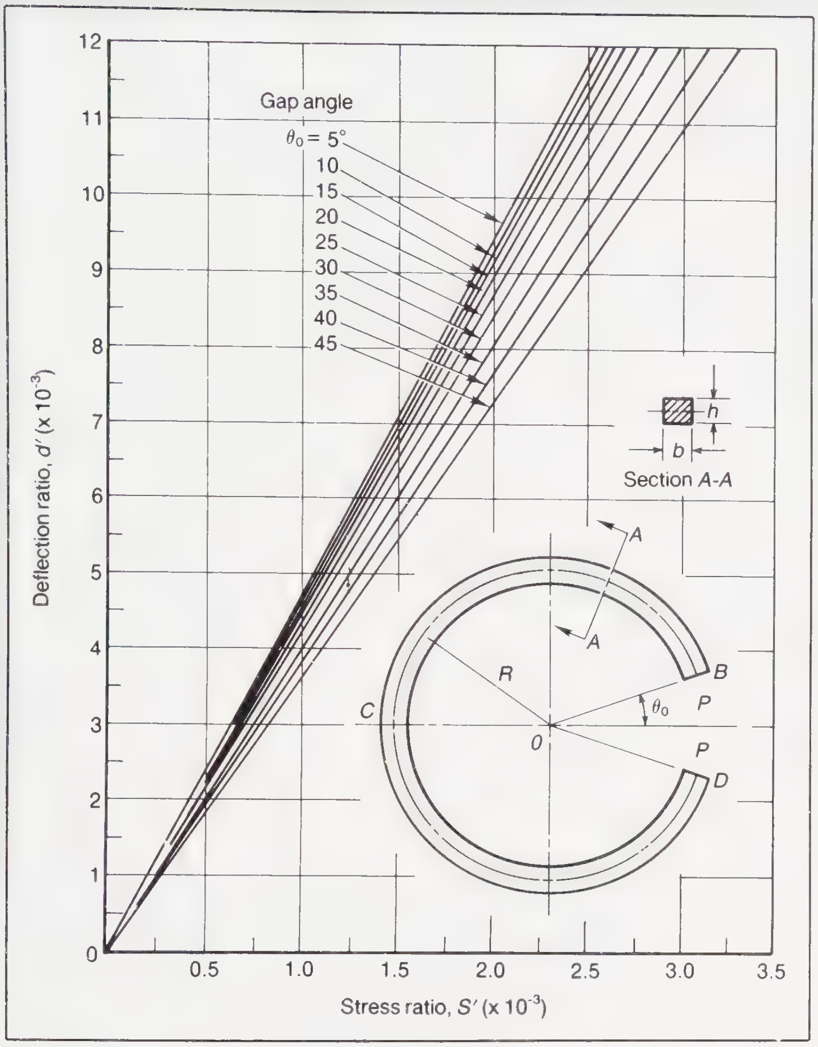
Sufficient design clearance should be allowed to assemble the rings with a minimum of effort. Radially assembled, or clip, retaining rings require accessibility to the side of the shaft. Rings used internally in bores require adequate space for tool insertion.

External closed rings are assembled axially over the end of the shaft. A radius or 30° chamfer on the end of the shaft greatly assists the assembly operation. A small edge margin also makes assembly easier.

Tolerances of ring thickness, groove location, and retained components may add up to cause objectionable end play. Tolerances can be taken up, to some extent, by using tapered-keystone or beveled sections. The narrow portion of the section thickness is in the groove, and the wide portion bears against the part.

External clip rings are easier to install than axially assembled rings, and require fewer tools. These rings are designed to be driven on gap ends first, over the bottom of the groove.

Axially assembled rings usually have better external appearance and higher



SIZING RING GAP

Size of a part accommodating a ring usually limits the size of wire-form retaining rings. Thickness, radial width, and radius are fixed; the real design problem is selecting an angular gap that provides the required deflection under load.

The graph and equations find the gap if the ring has a constant rectangular cross section; radial width of the spring is small compared to the main radius of curvature; the neutral axis of the ring coincides with the mean radius of curvature; and deflections under load are small, so the ring does not deform greatly from its initial circular shape.

To find the gap, these equations should be used:

$$d' = dh/R^2$$

$$S' = S_m/E$$

where d' = deflection ratio; d = total deflection of ring ends, in.; h = thickness of ring, in.; R = mean radius of curvature, in.; S' = stress ratio; S_m = maximum allowable bending stress, psi; and E = modulus of elasticity, psi.

The two equations give crossing lines on the chart. Gap angle is found at the point where the lines intersect.

rotational speed limits than the external clip rings.

Grooves for retaining rings vary according to the type of ring used and the type of service. Radius (rounded) grooves are used for round-section retaining rings.

For external rectangular-section clip and closed rings, groove width should be 1.15 times the ring-section thickness. This width is the absolute minimum that will accept standard rings. It may be desirable to specify larger minimums and tolerances to be consistent with design requirements.

Spiral-wound rings

Spiral-wound retaining rings consist of one or more turns of rectangular edge-wound wire. This provides a coil which can be installed or removed using automatic equipment or simple hand tools. When required, a 360° uniform thickness can be obtained by offsetting one material thickness at the coil ends.

The standard material for spiral-wound retaining rings is carbon spring steel. Some rings are available in other materials such as 302, 316, and 17-7 PH/C stainless steel, NS A286 alloy, beryllium copper, and Inconel X-750.

Time and stress greatly influence the allowable operating temperature. For those applications near the maximum temperature, the ring stress under load should be minimized by using a sharp-cornered retained part, a groove material with a high yield strength, and a ring from the series that uses the deepest grooves.

Carbon steel rings are normally given an oil-dip treatment to retard rust. Cadmium plating and phosphate coating are other standard finishes readily available. Specials include black oxide and parkerized finishes. Zinc, chrome, copper, and gold plates are also available. Plating adds approximately 0.002 in. to the maximum ring thickness.

Standard rings are available for shafts and bores ranging from 0.46875 to 15 in. in diameter. Rings for shafts and bores ranging from 0.375 to 72-in. diameters can also be manufactured.

Design considerations

Retaining rings fail in two ways: through shear, or from overstressing due to axial deflection. For shear failure to occur, the groove material must have a compressive yield strength greater than 45,000 psi; the load must be applied through a retained part that has a sharp corner and a yield strength greater than 45,000 psi; the ring must be thin in section compared to the ring diameter.

Under axial deflection the maximum stress on a ring subjected to uniform twisting is a tensile stress at the inner corner of the ring. If the ring is stressed past the yield point it will grow in diameter and become dished.

Retaining-ring manufacturers generally specify the maximum radius of chamfer on the retained part. Excessive chamfer sizes cause drastic reductions in allowable thrust loads.

The shallowest possible groove should be selected to minimize cost of the ring and of machining the groove, and to provide ease of ring installation. The minimum permissible groove depth is determined by:

- thrust load to be absorbed
- size of chamfer on the retained part
- yield strength of groove material in compression.

Rotation of a retained part against a spiral-wound retaining ring must be limited to one direction only — the direction that would tend to wind the ring into the groove. Spiral-wound rings are available in both left and right-hand winds.

SPIRAL-WOUND RINGS

Standard spiral-wound rings are inserted and removed using hand tools. Removal notch for external and internal rings is shown. Slotted ring can be used as an internal or external ring.

Special rings are available to meet many design requirements.

Locking tab keeps rings from spinning and is suitable for assemblies subject to rapid acceleration and deceleration.

Positive lock allows a much higher rotational speed than standard rings.

Prominent tab facilitates removal and is used where frequent disassembly is anticipated.

Spring tabs are used when the ring must exert a light load.

Dished ring takes up accumulated tolerance.

Washers

Washers are primarily used as a seat to distribute load, but they may also provide spring tension, span oversize holes, insulate, seal, or provide electrical connection. Various kinds include flat, conical, and helical-spring washers, tooth or ribbed lockwashers, and special-purpose washers.

Flat washers, also known as plain washers, provide a bearing surface for a nut or screw head, cover large clearance holes, and distribute fastener loads over a large area, particularly on soft materials. This, in turn, reduces contact stresses and can thus reduce relaxation.

Two types of washers are covered in ASME/ANSI B27.2 — 1965 for general use. Type A is a series of steel washers with broad tolerances, where design refinement is not important. They range from No. 6 to 3-in. hole size and from 3⁄16 to 5¼-in. OD. Type A washers are satisfactory for most assemblies.

Type B washers are of higher quality and are specified in narrow, regular, and wide diameters for each screw size from No. 0 to 3 in. ASME/ANSI B27.2 — 1965 gives washer, hole, outside, and inside dimensions. However, many other standard sizes are available.

Conical spring washers are used with screws to add spring take-up to screw elongation. Type L conical washers are designed for use with unhardened screws. Type H series is for hardened screws. Conical washers are designed to flatten at approximately one-half the ultimate load of the screw.

These washers are used with screws or bolts to increase the elastic properties of the joint. Screw and bolt connections loosen in different ways. Because the initial tightening is done by ap-

When your designs are hard to put together . . . fasten them with Bulb-tite® Blind Rivets from Olympic.

All aluminum, non-corroding Bulb-tite® blind rivets fasten thick or thin, hard or soft materials, even on curved or undulating surfaces. You can combine and fasten: metal sheets, foam cored panels, fiberglass, plastic, and wood without crazing, cracking or crushing. Hi-strength Bulb-tite® blind rivets can be ordered with a washer for watertight performance.

Bulb-tite® blind rivets can't strip out, back out, or be overdriven. The wide grip range means you stock fewer sizes of Bulb-tite® blind rivets than other fasteners.

Olympic Fastening Systems Division
GESIPA®
Fasteners USA, Inc.
610 Plum Street • P.O. Box 5068 • Trenton, NJ 08638
Phone: 609/396-5405 • TOLL FREE: 800-257-9404 • FAX: 609/396-1350

Circle 333

USA® TOLERANCE RINGS

Last year 13,000,000 of these corrugated metal fasteners solved design and production concerns by:

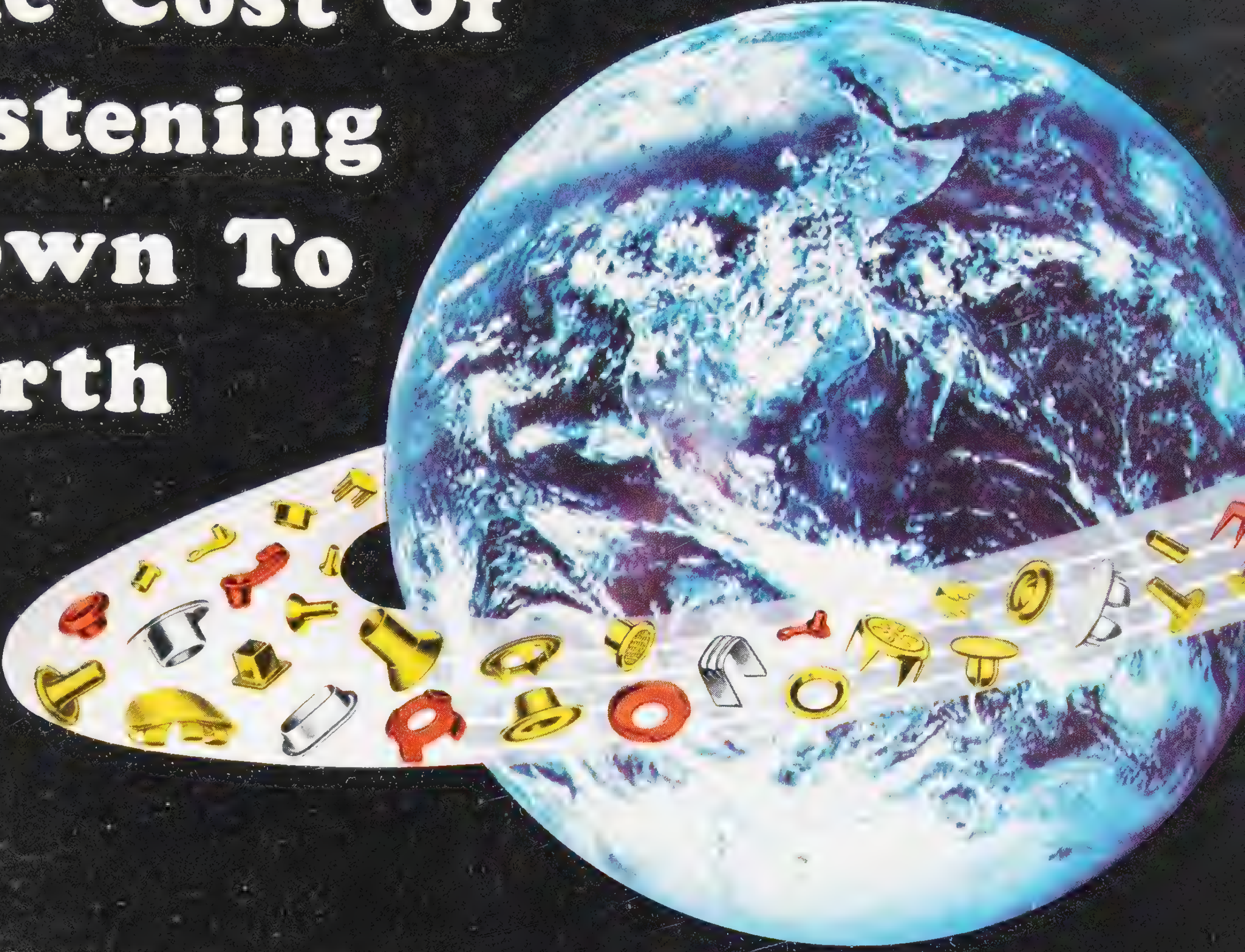
- Lowering production costs by relaxing dimensional tolerances of mating cylindrical parts in stampings, plastic molds and die castings
- Compensating for differential thermal expansion of dissimilar materials
- Absorbing misalignment
- Dampening vibration
- Providing a simple, efficient method for transferring torque from shafts to gears, pulleys, impellers and fans
- Eliminating the mess of glues and epoxies for fastening knobs, bushings and spacers onto shafts or into holes

USA TOLERANCE RINGS are available in diameters from 1/8 inch to over 1 foot; in widths of .020 inches up to 2 inches. Standard materials are stainless and carbon steel but USA TOLERANCE RINGS can be made from exotic alloys.

For more information and our free catalog, contact:
JOE TRAINER
USA TOLERANCE RINGS
P O BOX 7509
WEST TRENTON, NJ 08628
609-882-7380

Circle 334

Stimpson Brings The Cost Of Fastening Down To Earth



STIMPSON fasteners, known the world over for their high quality and reliability, offer you the versatility and savings you demand.

At STIMPSON, we maintain the industry's largest line of Standard and Specialty Eyelets, "C-E" Rivets, Grommets, Hole Plugs, Snap Fasteners and Stampings, available in a wide variety of metals, platings and finishes to meet your design specifications.

Backed by over a century of manufacturing expertise, our Assembly Service experts will analyze a sample of your product and assemble it by using the most economical and durable fastener to suit your product needs.

For more complete information, send today for your free copy of Stimpson's Designer's catalog, which illustrates over 1,000 Standard Fasteners and Stampings along with our full line of automatic attaching machines.

Stimpson
Co. Inc.

900 SYLVAN AVE., BAYPORT, NY 11705-1097
(516) 472-2000 • FAX (516) 472-2425 • TX-ITT-497-2370

Circle 335

plying torque, loosening is most often thought to be caused by the bolt or screw backing off. However, all metal and nonmetal components under a steady stress will show some amount of relaxation (creep, cold flow) — less for hard, smooth surfaces and more for softer and rougher surfaces. A similar effect results from differential thermal expansion/contraction, such as in many piping systems. The typical elastic elongation of a properly tightened screw or bolt is on the order of a few thousandths of an inch, and elastic compression of the clamped parts is usually even less. If the total relaxation approaches the initial elastic deformation, the clamping load will be almost lost. The joint loosens, although no reverse torque or backing off has occurred.

Properly selected spring washers may increase the elastic reserve of a joint by a factor of 10 or more. This means that relaxation that would cause 90% loss of preload without a spring washer will cause a loss of less than 10%.

"Belleville washer" is a term commonly, but incorrectly, applied to conical washers. The Belleville washer has precise dimensional relationships which give it greater spring action with load-bearing strengths comparable to a conical washer of the same size.

Some conical washers have an off-center circular plane, creating a secondary system which reinforces and increases the spring action of the basic coned washer.

Another conical washer with a flexible conical rim for initial loads and an arched secondary square cone for secondary loads gives more consistent clamp loads under a variety of conditions. A flat washer used in conjunction with a spring washer may often be replaced with this type of conical washer.

Helical spring washers are made of slightly trapezoidal wire formed into a one-coil helix so that the free height is almost twice the thickness of the cross section. They are usually made of hardened carbon steel, but are also fabricated from aluminum, silicon bronze, phosphor bronze, stainless steel, and K-Monel.

The most common regular helical spring washer acts as a spring when bolt tension is reduced. Bolt tension is maintained by the washer's expansion. When flattened, this washer becomes equivalent to a flat washer. However, these washers can flatten at as little as 10% of proper bolt load.

Tooth lockwashers are used with screws and nuts to add spring take-up to the screw elongation and to increase frictional resistance under the screw head or nut face. They bite into both the head of the screw and the work surface to provide an interference lock. Even at zero tension, the tooth lockwasher provides frictional resistance to loosening.

Rib washers (serrated safety washers) combine the significant spring properties of conical spring washers with the increased frictional resistance of tooth lockwashers. They are available in a variety of materials, and standardized in DOD-W-63464/3.

Special-purpose washers, such as the finishing washer, eliminate the need for a countersunk hole and are used extensively for attaching fabric coverings. The outer rim grips the material over a large area.

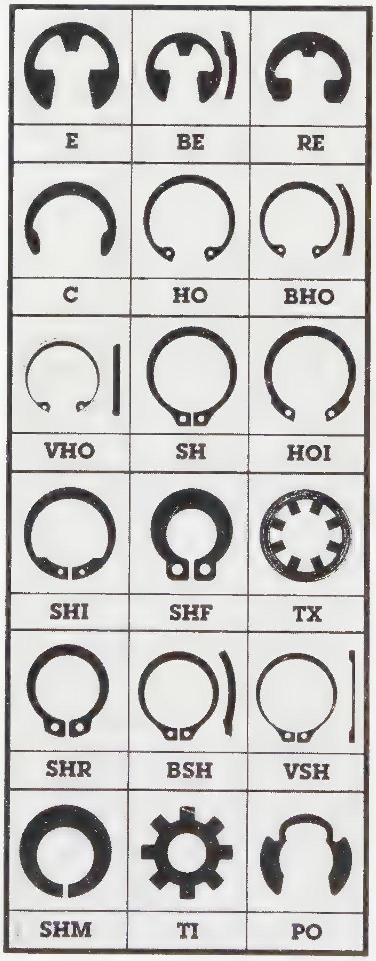
The fairing washer, an aircraft development, is used with flat-head screws on aluminum sinks. Holding pressure is spread over a large area, eliminating localized strains around the screws. The shape of this washer allows for flush surfaces. ■

ROTOR CLIP

The Full Line Retaining Ring Company

Inch, DIN, Wire-Formed Retaining Rings; Constant Section Rings; Retaining Ring Pliers/Applicators

FREE
72 Page
Catalog



ROTOR CLIP SPELLS QUALITY
"S..P..C.."

GM "Mark of Excellence" recipients plus Ford Q1 and Chrysler QE.

CALL TOLL FREE
1-800-631-5857

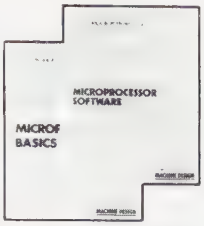
ROTOR CLIP®
ROTOR CLIP CO., INC.
187 DAVIDSON AVENUE, SOMERSET, NJ 08875-0461
(908) 469-7333 ● FAX: (908) 469-7898

We Keep America Together

Circle 336

INVALUABLE REFERENCES FOR YOUR TECHNICAL LIBRARY!

MICROPROCESSOR BASICS & MICROPROCESSOR SOFTWARE



A two-volume reprint series from Machine Design Magazine . . . 24 articles on topics such as anatomy of a microcomputer, developing software for micro application, and many more.

You may order this series by mailing the coupon below to:

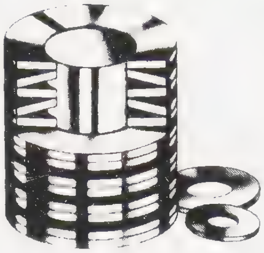
Penton Education Division
1100 Superior Avenue
Cleveland, Ohio 44114
(216) 696-7000

Please send me ____ copies of Microprocessor Basics & Microprocessor Software @ $20.00
☐ Payment enclosed for postage-free shipment (U.S. & Canada)
☐ Bill my company, P.O. enclosed
Charge my: ☐ MasterCard ☐ Visa ☐ American Express
Account No. ____
Expiration Date ____
Name ____
Title ____
Company ____
Address ____
City, State, Zip ____
Signature ____
Penton Education Division 1100 Superior Avenue Cleveland, Ohio 44114

THE BETTER BELLEVILLE

Precision Belleville Disc Springs

Over 500 Sizes In Stock!



- Heavier, Predictable Loading in Less Space
- Resists Fatigue, Won't Relax Under Load
- Stock Sizes — 3/8"-10" OD Specials and Metric Too!
- In Stainless, Inconel, and Other Special Materials

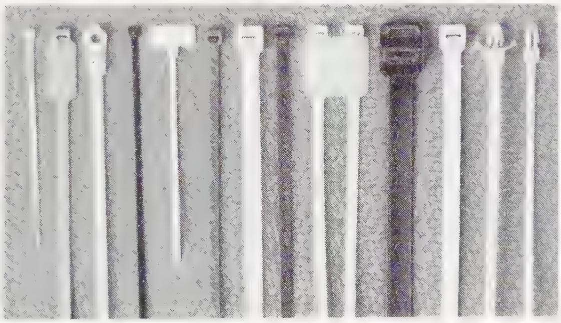
Call or write for our new, free, comprehensive catalog!

NOW! Rolex offers, without charge, a unique Design Guide on PC Diskette. Engineers can evaluate load and stress of single disc springs or stacks, for rapid and simple disc spring design.
• Call us, or order on company letterhead. •

ROLEX COMPANY
National Disc Spring Division
385 Hillside Avenue • Hillside, N.J. 07025
(800) 822-1922 • (201) 926-0900 • FAX (201) 926-5626

Circle 337

PANDUIT®
CABLE TIES



Widest Selection for Every Application
- High quality cable ties, backed by U.L. and Mil. QPL approvals.
- For bundle diameters from .060" to 13"; with tensile strengths from 13–600 lbs.
- Nine materials, 12 colors.
- Most complete line of accessories and tooling.

Another Panduit Idea to Lower Your Installed Cost

P QUALITY PANDUIT
ELECTRICAL GROUP

PANDUIT CORP UL REGISTERED FIRM ISO 9001 A2269

For more information call TOLL FREE 800-777-3300 ask for Ext. 1709

Tinley Park, Ill. 60477-0981 • FAX 708-532-1811

FREE SAMPLES

Circle 338

Versatile, Compact, Counterbalance

Conventional gas spring counterbalances are now used in aircraft, computers, business machines, industrial housings, furniture controls and other systems requiring compact installation, controlled action, and cost savings.

New technologies enable the designer to specify:

Intermediate Locking, Tension/Compression Systems.

Stabilus offers complete design services tailored for large and small programs as well as computer evaluation, cost analysis, etc.

If you have a design objective . . . consider a gas spring. Write for free technical data.

STABILUS
Formerly Gas Spring Company

92 County Line Road • Colmar, PA 18915 • Tel. 215/822-1982
Division of Fichtel & Sachs Industries, Inc

Circle 339

Special-purpose fasteners

Fasteners are available to fill special functional or material requirements.

Special-purpose fasteners are available for applications in which standard fasteners are inappropriate or insufficient. Materials such as spring steel, hot or cold-formed metal, or plastic may be used for such fasteners as clips, clamps, and cable ties. Quick-operating fasteners are used where quick or repeated access to a component is necessary. Self-sealing fasteners can help keep gases and liquids in or out of an assembly.

Choosing special fasteners

There are several design factors to consider when choosing specialty fasteners. These include:

Communication: Early supplier input will guarantee sufficient lead time to design the fastener, conduct tests, and make necessary alterations.

Underengineering: A purchase should not be made solely on price. The fastener may be improper for the particular application or too frail for the job. Do not specify a single-thread fastener where a multiple thread is necessary. Do not use an existing fastener for an application that requires a specially designed fastener.

Overengineering: Do not request metal that is too heavy for an application, critical tolerances where they are not needed, or oversized nut-and-bolt combinations.

Finish: Choose finish after the supplier studies the problem. Finish hardness should be based on application.

Material: Match the grade of steel to the application. Be particularly aware of gage thickness.

Fastener function: Clearly specify what the fastener will do when ordering. Be aware of fastener limitations.

Servicing: Before ordering, know if the fastener will be removed. If so, determine how often it will be removed and if special tools will be required.

Assembly techniques: Be sure a requested fastener is compatible with existing automatic assembly equipment. But do not compromise fastener reliability for assembly speed.

Marketing: There may be delays when ordering fasteners made of hard-to-get materials.

Order size must be evaluated carefully. Once an order is placed, some suppliers may not be able to handle high-quantity runs on short notice.

Spring clips

Typical spring clips are self-retaining, one-piece fasteners that slip into a mounting hole or onto a flange or panel edge. Secondary fastening devices such as rivets, studs, or screws are not needed because the clips are held by spring tension and do not loosen easily through vibration. The clips also compensate for tolerance buildup and misalignment.

The basic spring-clip material is steel with 0.50 to 0.80% carbon. Generally, fasteners are hardened to Rockwell C 45-50. Varied spring tensions are obtained by controlling the width and thickness of the steel.

Some other metals are used but cannot match the spring properties of high-carbon steel. Plastic fasteners have replaced metal spring clips in many applications. However, plastic designs are limited by their holding capabilities and by some environmental conditions.

Coatings can be used to meet special requirements. For example, on metal parts, neoprene and vinyl dips provide a soft cushion to prevent chafing and damage. Zinc mechanical plating also provides an attractive finish without danger of hydrogen embrittlement.

Many plastic clamps and fasteners are self-retained to panels by an integral dart shape, an expandable leg, or high-strength contact adhesive.

Dart-shaped, panel-retaining spring clips have "hips" to engage within panel or component holes. They are commonly used to join two panel surfaces, as in refrigerator door liners. Other configurations are used to fasten cables, molding trim, gaskets, and fabrics. Most dart-type clips are easily removable and require a mounting hole and space behind the mounting panel to accommodate the dart.

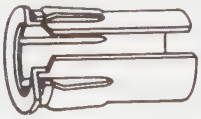
Dart-type clips may be installed with finger pressure for light duty or with power tools for heavy applications.

Stud receivers

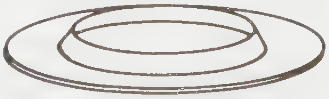
Push-on, tubular, and self-threading

STUD RECEIVERS

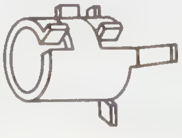
Flange and spring-loaded fingers bite on stud to hold tubular clip in place.



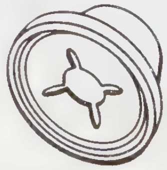
Thin-wall stud receiver used for 0.05 to 0.625-in.-diameter studs in limited-access applications.



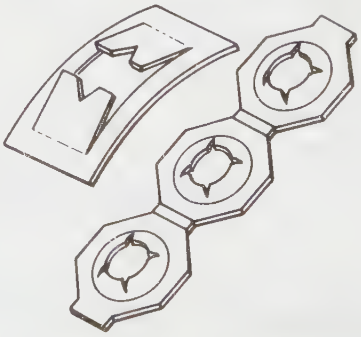
Fingers on receiver are squeezed together to remove clip.



Cap-type receiver can decorate and protect as well as secure. Available in metal or plastic.



Push-on receivers are available in strip form for automatic assembly.



What we've learned while designing those 15,000 fasteners can help you in a number of ways.

Our sixty years of experience making Tinnerman® brand fasteners mean we can carry your project through from early sketches, to design, early prototype and mass production with a minimum of delays.

So you get fasteners on time.

You get fasteners on budget.

And you get fasteners you can count on.

For more information, write: Eaton Corporation, Engineered Fasteners Division, Service Center, P.O. Box 6688, Cleveland, OH 44101.

After all, if your application demands a unique single-piece, multiple-functioning or complex-assembly fastener, you should talk to the people who've designed more of them than anyone else.

EATON

Circle 340

stud receivers attach to unthreaded studs, rivets, pins or rods of metal, plastic, or wood. Stud receivers are usually made of hardened and tempered high-carbon spring steel.

Push-on stud receivers are made in flat or round styles, with two or more prongs that allow the fastener to be forced down on a stud and locked in place. Back pressure against the fastener causes the prongs to bite deeper into the stud. They can be designed to be either removable or permanent and are available in shapes that receive D, square, or other stud forms. Some are covered with a metal or plastic cap for protection or decoration.

Tubular spring clips have a split tubular sleeve for securing unthreaded assembly members. They are used where only one side of an assembly is accessible and a stud member can be incorporated. Examples are nameplates, decorative trim, and knobs.

Most tubular clips require panel-mounting holes or cavities within the mounting panel. Pressed into position as an assembly, the tubular clip is self-retained and permits front mounting of the stud member.

Self-threading stud fasteners form their own thread as they are turned down on unthreaded studs of die-cast zinc, aluminum, or plastic. The spring action of the nut body, plus the interference fit produced by the thread-forming flutes or teeth, provides strong prevailing torque to hold the nut firmly.

Open and shut case for good design.

If your product depends on hinges, it deserves the neat appearance and long term reliability that product designers look for when they're looking for the finishing touch.—That means you'll want Stocker hinges.

Stocker helps you design exactly what you need. In fact, if we don't aleady have what you want, we'll work with you to provide a hinge that meets your exact specifications.

When designers look for something better—unusual configurations, special finishes, unique construction—Stocker is the manufacturer who presents an open and shut case. Write or call today for our newest Engineering Catalog: Stocker Hinge Mfg. Co., 8822 West 47th St., P.O. Box 149, Brookfield, IL 60513. (708) 485-3400. Fax: (708) 485-0058

STOCKER HINGE

Circle 341

Cable and tube retainers

Retaining elements to hold wires or tubing are incorporated into these fasteners that engage panel holes, mounting flanges, or panel edges.

The fasteners are front mounting, and require no access to the back of the panel. One spring clip can often replace several loose parts. Because they fasten through spring tension, they compensate for normal tolerance variations and misalignment, and will not vibrate loose.

Shaped spring clips

Spring clips use compressive spring force to secure assembly components. The clips come in many shapes and sizes to accommodate a variety of plastic and die-cast parts.

U-shaped clips are used to assemble cover panels, breaker trim, flange and channel assemblies, wire and cables, glass panels, armored cable, hinged components, and rubber and fiber.

S-shaped clips fasten panels and flanges in line with each other, or at an angle with these clips. They are particularly useful in assembling plastics and other soft materials in blind or hard-to-reach areas.

C-shaped and compression-ring clips have compressive action to hold plastic knobs firmly on steel shafts and permit their ready removal and reuse.

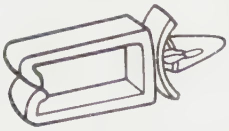
Formed-metal fasteners

Typically, metal special fasteners are more costly than standards because they are made through hot or cold forming. This requires more precision, manufacturing operations, highly skilled workmen, and initial engineering. The payoff is in performance and lower cost.

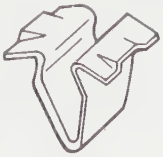
Metal special fasteners are divided into two general categories. First, there are modified standards or fasteners

DART-TYPE CLIPS

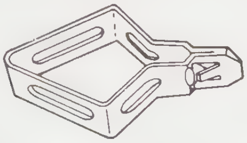
Wire retainer has a top-loading feature and dart-type retainer.



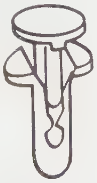
Lips on clips allow fastener removal with screwdriver blade or pliers.



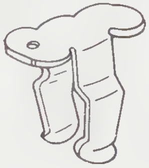
Clip with dart retainer holds ceramic insulator for heating coil.



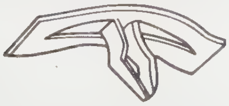
Reusable plastic dart is used where insulating properties are needed or to accommodate variations in panel thickness.



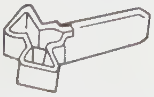
Heavier-gage metal gives clip more holding strength.



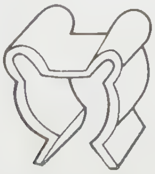
Thin-metal clip is designed for light loads and delicate items.



Head of clip retains miniature lamps.



C-clip retains a D-shaped shaft in a knob. Clip provides multipoint contact within the knob hub and a long-wearing surface.

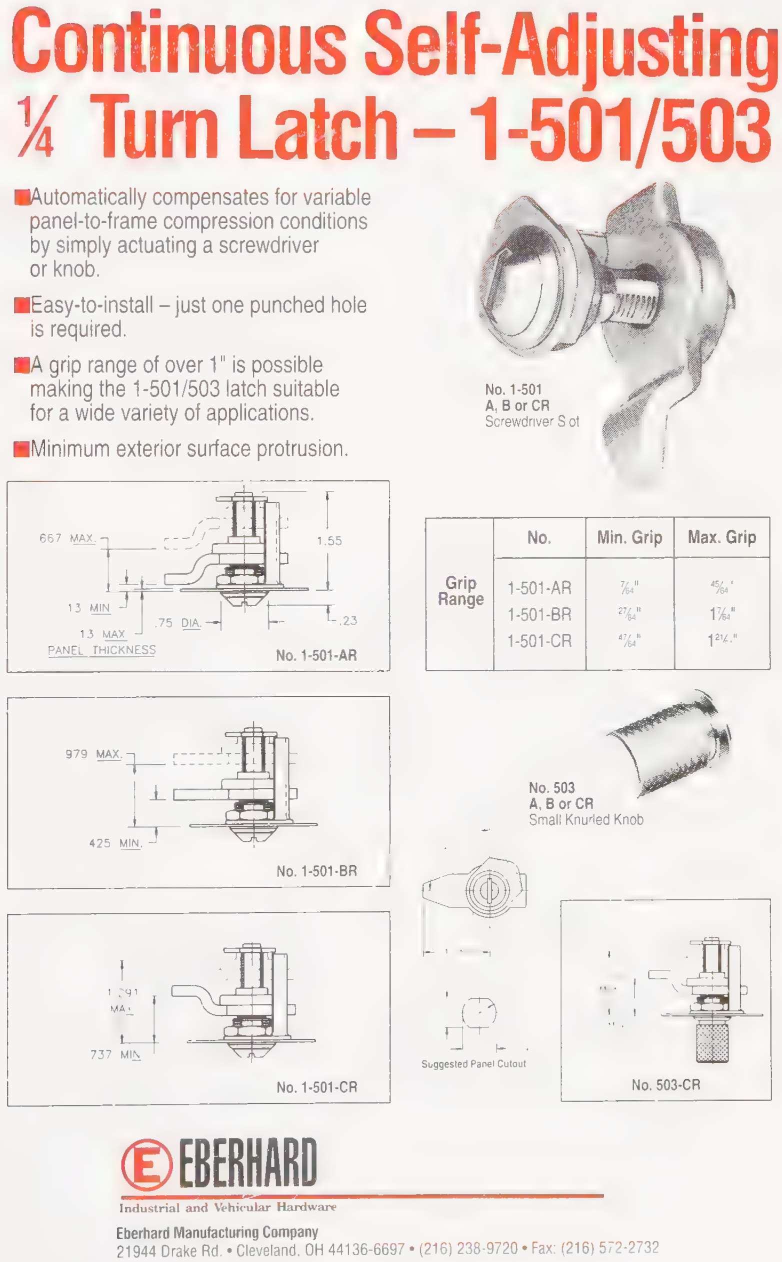


that look much like standards, but have been changed slightly in shape or mechanical properties to meet a specific need. For example, a standard hex bolt may be specially hardened or lengthened or have a slot machined in its tip. The other type of special might be called a multiple-function fastener. These fasteners perform some function in addition to fastening. They are incorporated into gears, cams or levers, or contain some other machine element critical to the product.

Plastic fasteners

Threaded and nonthreaded conventional plastic fasteners have the same dimensional thread class and fit standards as those for metal fasteners. Sizes range from 00 to ¾ in. in diameter and in lengths up to 6 in. Threaded plastic fasteners include bolts, screws, rods, studs, and nuts.

Nonthreaded plastic fasteners are generally classified by product families and include rivets, washers, pin fasteners, quick-operating fasteners, re-



Continuous Self-Adjusting ¼ Turn Latch – 1-501/503

- Automatically compensates for variable panel-to-frame compression conditions by simply actuating a screwdriver or knob.
- Easy-to-install – just one punched hole is required.
- A grip range of over 1" is possible making the 1-501/503 latch suitable for a wide variety of applications.
- Minimum exterior surface protrusion.

No. 1-501
A, B or CR
Screwdriver Slot

No. 1-501-AR

	No.	Min. Grip	Max. Grip
Grip Range	1-501-AR	7/64"	45/64"
	1-501-BR	27/64"	1 7/64"
	1-501-CR	47/64"	1 21/64"

No. 1-501-BR

No. 503
A, B or CR
Small Knurled Knob

No. 1-501-CR

Suggested Panel Cutout

No. 503-CR

EBERHARD
Industrial and Vehicular Hardware
Eberhard Manufacturing Company
21944 Drake Rd. • Cleveland, OH 44136-6697 • (216) 238-9720 • Fax: (216) 572-2732

Circle 342

Plastic fastener material properties

Properties	**ABS**—Thermoplastic offering the best balance of properties of common rigid thermoplastic material — good impact strength, good heat resistance, good low-temperature properties, excellent electrical properties, and fair-to-good chemical resistance. Plateable grades available.	**Acetal**—An engineering thermoplastic that offers strength, rigidity, and good moisture, heat, and chemical resistance. Excellent abrasion resistance.	**Fluorocarbon (TFE)**—Used where extreme corrosion resistance is required. Also unusually stable at high temperatures. Has low dielectric loss and constant. Disadvantage is low tensile strength—1/10th that of nylon.	**Nylon 6/6**—Most common material for standard plastic fasteners. Structurally strongest of all nylons, 6/6 features low coefficient of friction, good insulating properties, self-extinguishing, resistance to heat, shock, vibration, and chemical solvents. It is light, elastic, and has superior torque strength.	**Polycarbonate**—Mos desirable balance of properties of any thermoplast material available—exce lent high and low temperature strength, good heat r sistance (up to 250°F unde load), high impact strengt (in — 275 to + 250° range), excellent dimensional stability, non-toxi and excellent electrical insulation.
General					
Specific gravity	1.02	1.42	2.12	1.14	1.2
Water absorption 24 hr @73F (% gained)	0.20	0.25	0.00	1.5	0.15-0.18
Mechanical					
Tensile strength (psi)	3,500-6,200	10,000	2,000-5,000	9,000-12,000	8,000-9,500
Elongation (%)	5.0-60.0	25 injection molded	200-400	60-300	100-130
Flexible strength (psi)	6,000-10,000	14,100		no break	12,200-12,700
Hardness Rockwell R	R-75-105	R120	R84	R108	R118
Electrical					
Volume resistivity, Ohms/cm (50% RH and 23 C)	1.0×10^{15}	$1.0\text{-}4.8 \times 10^{16}$	2.5×10^{16}	4.5×10^{13}	2.1×10^{16}
Dielectric strength, Short time ⅛ in. thickness (v/Mil)	350-500	380	495	385	400
Thermal					
Thermal conductivity (Btu-ft/hr sq ft-°F)	0.11	0.13	0.15	0.14	0.11
Specific heat (Btu/lb-°F) 0.3-0.5		0.41	0.35	0.22	0.30
Thermal expansion (10^5 in./in.-°F)	5.8	4.5	4.8	5.0	3.9
Environmental resistance					UL Class I & II
Effect of weak acids	None	Resists some	None	None	None
Effect of strong acids	Attacked by concentrated oxidizing acids	Attacked	None	Attacked	Slowly attacked
Effect of weak alkalies	None	Resists some	None	None	Limited resistance
Effect of strong alkalies	None	Not recommended	None	None	Attacked
Effect of organic solvents	Soluble in ketones, esters, some chlorinated hydrocarbons	Excellent resistance	None	Resists common solvents, but dissolved by phenols and formic acid	Resistant to paraffinics, soluble in aromatic and chlorinated hydrocarbon

taining rings, inserts, spacers, clips, harnesses, clamps, wire bundlers and ties, snap inserts, and grommets.

Plastic fasteners are considered for applications where environmental, thermal, optical, weight, chemical, and electrical properties are a significant consideration for end use.

Plastic materials meet a broad spectrum of design requirements — strength, rigidity or flexibility, heat, low temperature, chemical and corrosion resistance, sealing, toughness, good electrical properties, and light weight.

Common plastic fastener materials are often less costly than their metal counterparts.

Plastic fasteners can have special functions, in addition to being available in standard shapes. Integral color, special undercuts, and molded-in metal inserts are a few of the possibilities.

Assembly can be simplified when a single plastic fastener replaces several metal components.

A plastic fastener must be evaluated not only on the material to be used, but on the intended application as well. Physical, mechanical, thermal, environmental, and electrical properties must be considered. Interaction of the plastic with other materials is also a potential problem.

In the evaluation of plastic for use in a fastener, the designer should be aware that new forms of plastic can be created by alloying, varying the processing techniques, or adding fillers, lubricants, or reinforcing materials.

Plastic fastener materials can have a glass or metallic filler added to the base resin to improve strength, stiffness, useful temperature range, and specific gravity. Therefore, the designer should consult his fastener supplier for assistance in selecting the best plastic material and fastener for each application. Plastic fasteners, like most specialty fasteners, are often available in custom versions. Manufacturers may be able to

Polyethylene—Low-cost, medium-strength material. Good insulator and has "rubber-like" characteristics. Can be used for temperature applications to 190°F.	**Polypropylene**—Lightest of the thermoplastics. Excellent chemical, heat, and electrical resistance properties; is original "living" hinge material. Main disadvantage is low-temperature brittleness. Plateable grades available.	**Rigid PVC**—Used for many special fastener applications. Exceptional resistance to acids, alkalies, and alcohols. Excellent in corrosive applications. Self-extenguishing. Will not impart taste or color to materials handled. Good abrasion resistance.
0.940-0.965	0.90-0.91	1.35-1.49
≤0.01	0.30	0.10
3,100-5,500	4,300-5,500	5,000-9,000
20-1,000	200-7,000	2-40
	6,000-8,000	10,000-16,000
D63	R95	R113
≥10^{15}	10^{17}	≥10^{16}
450	500	1,413
0.15	0.08	—
0.55	0.46	—
9.0	6.0	3.5
None	None	None
Slowly attacked by oxidizing acids	Slowly attacked by oxidizing acids	None to slight
None	None	None
None	None	None
Resistant (below 80 C)	Resistant (below 80 C)	Resists alcohols, aliphatic hydrocarbon, and oils; soluble or swells in ketones and esters; swells in aromatic hydrocarbons

provide a wide range of plastics as well.

In addition, plastic fasteners may be able to combine the advantages of their metal counterparts with advantages of their own. For example, several plastic fasteners are designed similarly to standard blind rivets. However, plastic permits several variations on this theme. Available designs can be inserted by hand or removed and reused. Drive-pin, threaded-pin, and pull-mandrel styles are available.

Advantages of plastics in these cases include the potential for use in soft materials, especially when fasteners have a broad bearing surface; a wide range of material colors; and elimination of galvanic corrosion. In addition, plastics are nonconductive, making them useful in electrical and electronic applications.

Quick-operating fasteners

These fasteners should be used when repeated access to a component is necessary. When selecting these fasteners, important factors include strength of construction, smoothness of operation, and ease of installation. Speed can be a consideration if many fasteners are involved. Simplicity of fastener design and operation can also be important. For example, a quick-release fastener with a Phillips recess offers fast access only if an operator has the required screwdriver.

Seven types of quick-operating fasteners include: lever-actuated, turn-operated, slide-action, push-pull, lift-and-turn, magnetic catches, and spring-loaded devices.

Lever actuated: Draw-pull catches have a U-shaped wire bail or a flat spring-steel J-hook connected to a lever that pivots within a housing bracket mounted on one element of the closure assembly. Others have an engagement point built into a combined lever/cover that conceals all the catch assembly components in order to protect the lock and present a clean appearance.

The keeper is the element that engages the bail and is usually on the movable element of the closure assembly. These fasteners pull the two elements together tightly and lock by means of an overcenter linkage.

Some lever-actuated fasteners have coil springs or an adjustable threaded hook. These features compensate for installation inaccuracies, wear, gasket set, or damage.

The cam-actuated fastener has a cam which engages, pulls in, and locks a pin mounted in a separate keeper. The cam can be an inherent part of the

COLD FORMING

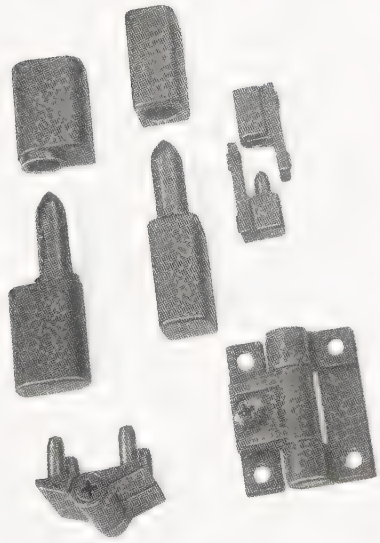
Automation has created the need for parts that not only fasten but may perform some other function, such as provide reinforcing or act as a spring. Cold forming can save both materials and machining costs because the part is formed to its final shape in the die. In addition, cold-formed parts are frequently stronger because the process produces grain orientation that follows the part shape.

Generally, the softer the material, the easier cold forming is to carry out. Generally, low and medium-carbon steels are easiest to form. Steels above 0.5% are more difficult. Other materials can be formed with varying degrees of complexity. Each must be evaluated relative to part complexity.

Some materials respond well to "warm forming" where the metal is heated to a temperature of no more than 900° F before forming takes place. This preheating allows both easier forming and greater stress relief in the part.

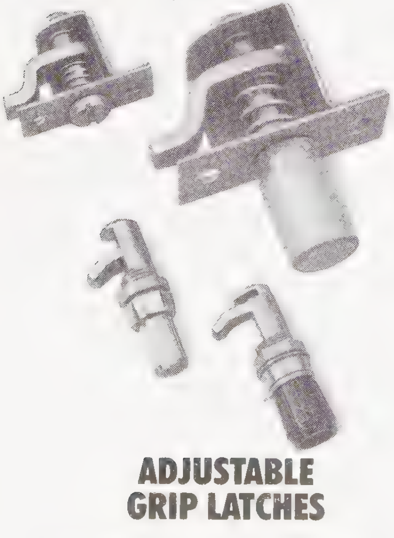
Manufacturers' capabilities play a large part in determining the economics of going to a cold-formed part. There are proprietary variations on the three conventional basic processes: upsetting, forward extrusion, and backward extrusion. Minimum quantity is also a major consideration because special dies usually must be made.

HOW TO
JUST ABOUT



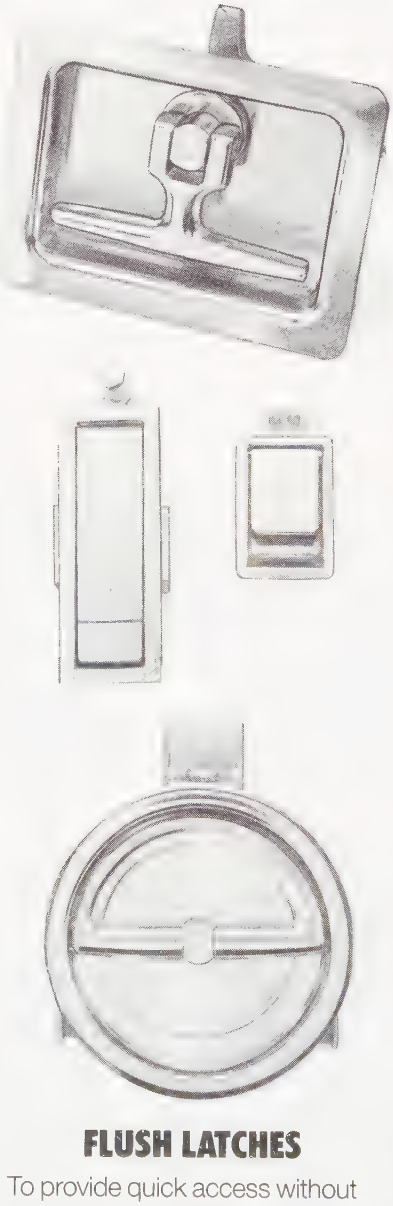
SPECIALTY HINGES

Lift-off hinges for quick access and adjustable friction hinges to help hold doors open.



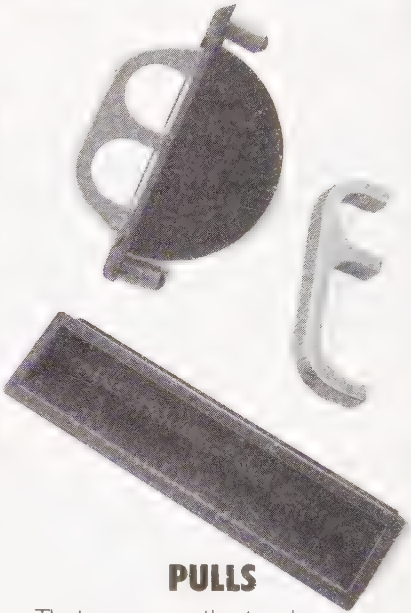
ADJUSTABLE GRIP LATCHES

Compress gaskets, eliminate rattles, or accommodate variations in panel thickness.



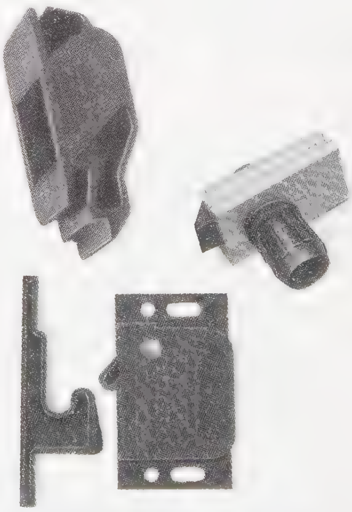
FLUSH LATCHES

To provide quick access without the obstacle of protruding handles. Operated by turning, pushing, or lifting.



PULLS

That permanently stand off the surface, fit flush, or pivot to a stored, flush position behind the surface.



SLAM ACTION LATCHES

Latch and engage automatically when you push your door closed.

ACCESS ANYTHING.

QUARTER-TURN FASTENERS

A variety of headstyles and receptacles for dependable service in nearly any application.

VISE-ACTION™ LATCHES

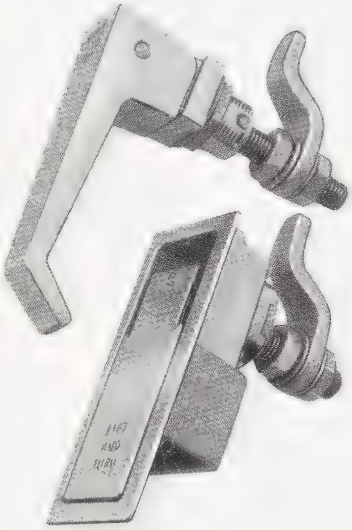
Provide latching and compression in one smooth fluid motion of less than 3/4 of a turn.

DRAW LATCHES

Provide secure, dependable overcenter latching in a range of sizes, materials, and features.

CAPTIVE SCREWS

Help eliminate lost or misplaced hardware in a variety of styles, thread sizes, and features.



LIFT & TURN LATCHES

Assure proper pawl position and provide consistent, preset compression.

In addition to offering industry's broadest line of assembly and design fasteners, Southco also offers SPC and JIT programs, on-site application reviews, product samples, product modifications, telephone customer service representatives and customer service engineering, national and international distribution, and a lot more. For a copy of the Southco Fastener Handbook, phone, FAX, or write to Southco.

SOUTHCO®
fasteners

SOUTHCO, INC., 237 Brinton Lake Rd.
Concordville, PA 19331
TEL: 215-459-4000
FAX: 215-459-4012

Products designed with your customers in mind.

fasteners file

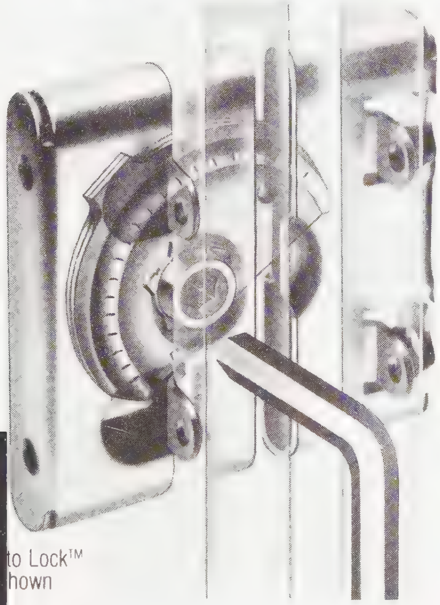
Southco Fasteners
for all your access needs

© Southco, Inc.

Circle 343

SIMMONS FASTENING TIPS

HOLD PANELS TIGHT WITH SIMMONS ROTO LOCK™ OR DUAL LOCK™!



• Butt-joint fasteners quickly draw panels together—capable of providing airtight/watertight seals • Positive locking with up to 1,200 lbs. tension, Roto-Lock,™ — 4,500 lbs., Dual Lock™ • Fasteners can be recessed completely within your panel • Roto Lock™ and Dual Lock™ can be front or side mounted. Tab version Roto Lock™ can be back mounted for hidden installation • Vibration and impact resistance; heavy duty performance • For more information, phone, Fax, or circle the reader service number.

Simmons Fastener
1750 North Broadway, P.O. Box 1985
Albany, New York 12201
TEL: 518-463-4234 • FAX: 518-463-0360

SIMMONS

Circle 344

lever, or it may be a separate component interconnected by a housing.

The draw-pull catch is designed for use on boxes or chests with coplanar surfaces at the parting line of lid and body. It provides moderate strength across the parting line. The spring-loaded type also has good vibration and impact resistance and requires less care to install, but costs more.

The adjustable catch tolerates greater errors at installation, permits future readjustments, and provides a solid high-strength pull down across the parting line because it has no springs. This fastener is not intended to carry loads in the planes of motion perpendicular to the parting line or along it because the lids of boxes and chests usually are fitted over mating edges. The draw-pull catch is an excellent fastener for gasket compression on container lids, hinged covers, dust-collector units, and for use on electrical control boxes where specifications will not permit fastener components to extend into the box.

Turn operated: Several types of turn-operated fasteners are available. Stud members and a retaining device, such as a nut, make up stud-type fasteners. This fastener may have multiple threads, a single fast-lead thread, or a projecting lug arrangement. They accomplish engagement, compression, and hold down.

Pawl-type fasteners have a rotatable stud or shaft with a radially projecting pawl. The shaft is mounted through the removable panel, and the pawl engages behind the frame or supporting member. The fastener compensates for a range of material thicknesses by using a threaded shaft on which the pawl moves axially when the shaft is rotated, or it may have a fixed adjustment, in which the pawl slides along the shaft and is locked in place with a nut or setscrew. The first type provides more compressibility or pull-up and is intended for use with gaskets or where very tight lock-down is desirable. The second type operates faster.

The quarter-turn panel fastener is designed for access panels, hinged doors and plates, removable signs, large structural panels, and other applications whenever the movable (or removable) panel overlaps the supporting member, and where very rapid removal or frequent access is necessary.

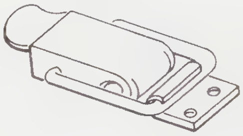
Although they provide excellent ultimate tensile strength, these fasteners characteristically are spring loaded to engage and lock in a quarter turn. For this reason, they have low plate-separation load characteristics up to the distance required to fully compress the spring. If rigid, boltlike characteristics of plate separation (sometimes called yield or initial tension) are necessary, a threaded screw fastener with fast-lead thread or an adjustable-pawl fastener should be used.

Slide action: A boltlike member is moved across the edge of the closure to

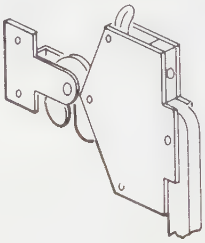
QUICK-OPERATING FASTENERS

LEVER ACTUATED

Draw-pull, bail-type fastener has good leverage for pulling adjoining sections together. Used for edge-to-edge applications, it has no parts within the assembly.

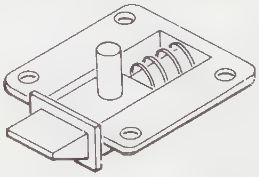


Cam-action fastener has good resistance to shock and vibration. Quick-disconnect feature can also make or break a circuit.

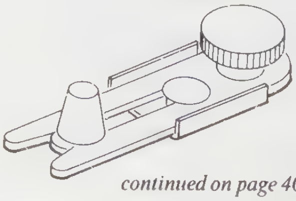


SLIDE ACTION

Spring-loaded bolt is mounted internally. Fastener does not compress panel or cover against the frame.



Snap-action latch has a slide on the removable section which engages a stud on the fixed section. Fastener resists shock and vibration.



continued on page 400

Machine Design

reprints mean business.

Let us put them to work for you.

Reprints of your advertisements and "Machine Design" articles can be used as:

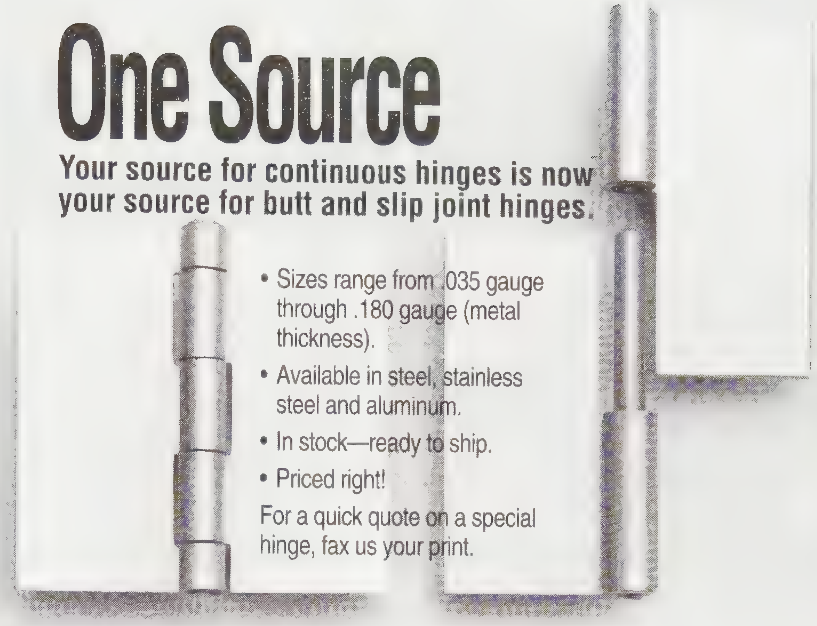
- ☞ *Direct mail to customers and prospects.*
- ☞ *Sales aids for your people in the field.*
- ☞ *Tools to inform stockholders and employees.*
- ☞ *Training aids for new employees.*
- ☞ *Handouts at trade shows and company meetings.*
- ☞ *New product announcements.*
- ☞ *Follow-ups to ad inquiries.*

For more information about this cost-effective way to get your message out to your customers and staff or to place an order, call Linda L. Fouts, reprints manager, at (216) 696-7000.

MACHINE DESIGN
is a publication of:
Penton Publishing
1100 Superior Avenue
Cleveland, Ohio 44114

One Source

Your source for continuous hinges is now your source for butt and slip joint hinges.



- Sizes range from .035 gauge through .180 gauge (metal thickness).
- Available in steel, stainless steel and aluminum.
- In stock—ready to ship.
- Priced right!

For a quick quote on a special hinge, fax us your print.

Marlboro
MANUFACTURING, INC
11750 Marlboro Ave. • Alliance, OH 44601
(216) 935-2445 • Fax: (216) 935-2748

Fits All

Circle 345

If It Has Threads We'll Lock It!

For variety, nobody beats Long-Lok.

T-Sert [illegible]

Long-Lok [illegible]

Poly-Lok * Polyester patch type usable to 400° F Qualified to MIL F-18240 NAS MS AN and IFI requirements

Dri-Loc * Pre-applied microencapsulated anaerobic adhesives to your specifications

Dyna-Thred II All metal for high vibration and temperatures to 1200 F. For critical assemblies

Tek-Lok [illegible] provide econom[illegible]

[illegible]

Call for FREE samples!

Long-Lok Fasteners
10630 Chester Rd., Cincinnati, Ohio 45215 • 513 772-1[illegible]
13709 S. Normandie Ave., Gardena, Calif. 9024[illegible]

Circle 346

engage within, or under, a keeper element mounted to the frame or body of the structure. In some cases, the keeper is not used, and the bolt engages directly into the surface of the frame or panel. Some types are mounted entirely on the outside of the panel-frame structure.

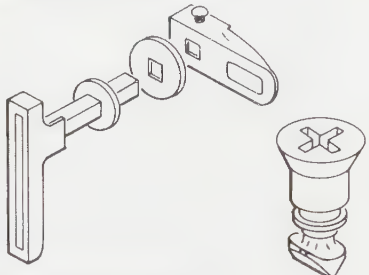
Some slide-action fasteners are manually operated with a push, turn, or pull action. Others are spring-biased to latch when the panel closes.

The slide-action fastener converts loads on the panel to shear within the fastener and restricts motion in at least two directions. Some types have an ad-

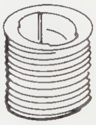
continued from page 398

TURN OPERATED

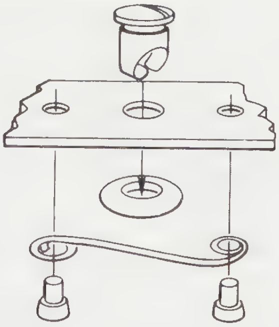
Pawl-type fastener is used for door and frame applications. Easily installed, the fastener can be set to various door thicknesses.



Threaded-receptacle, quarter-turn fastener is used for covers or panels. Receptacle is threaded into a blind or through hole.

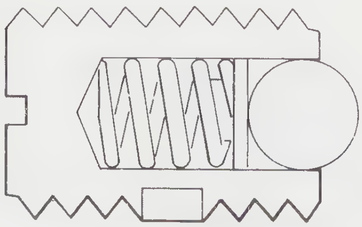


Quarter-turn fastener engages locking spring in panel. Retainer must be riveted or welded in place. A variety of heads are available.



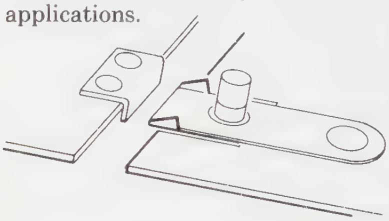
SPRING LOADED

Plunger provides end forces for detent or to hold parts in place. Device is installed in the same way as an insert.

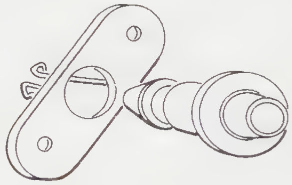


PUSH-PULL

Button latch has hooked lever which engages a lip on the fixed panel. It is used for quick latching in light-load applications.

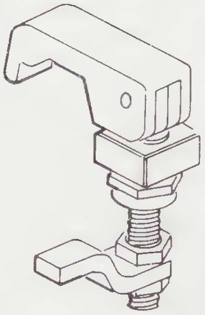


Pin-spring latch engages when the conical pin on the movable panel engages spring fingers on the fixed section. Finger pressure on the pin unlatches the fastener by spreading the retainer-spring finger.



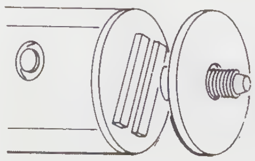
LIFT AND TURN

Compression of the panel to the frame is possible with this fastener. Lever actuation gives a visual indication of a locked or unlocked condition.



MAGNETIC

Fastener offers the advantage of no moving parts to wear. It is used for light loads and where no positive mechanical frame-to-panel connection is required.



SIMMONS FASTENING TIPS

AT LAST, A DRAWLATCH WITH A KEY LOCK!

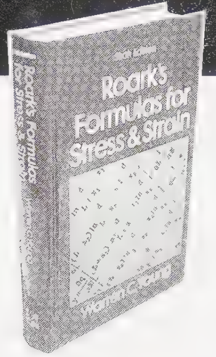
• New key lockable Link Lock™ offers selective security, rugged, reliable, positive, over-center latching, and compensation for up to 4.0 mm/.16″ misalignment • Another new Link Lock™ offers a low-profile, a full 6 mm less than any similar latch • Both are offered in bright zinc or black finish • Over 1,000 other Link Lock™ versions available including stainless and padlockable • For more information, phone, Fax, or circle the reader service number.

Simmons Fastener
1750 North Broadway, P.O. Box 1985
Albany, New York 12201
TEL: 518-463-4234 • FAX: 518-463-0360

SIMMONS™

Circle 347

STRESS ANALYSIS ON YOUR PC USING ROARK & YOUNG'S BOOK "FORMULAS FOR STRESS & STRAIN"


Sixth Edition
Roark's Formulas for Stress & Strain
Roark's Formulas for Stress & Strain
Warren C. Young

Since 1938 Roark's *Formulas for Stress & Strain* has maintained its position as one of the most widely used engineering reference works in the world. Now 37 tables, over 1400 cases and more than 5000 formulas from the new 6th Edition of this book are combined for the first time with the power of TK Solver software

The program covers the entire 6th Edition of the book • Provides stress and strain solutions for beams, plates, columns, and pressure vessels • Handles superposition of loads • A set of unit conversions and an expandable materials library are included • Program menuing system helps you select the particular chapter, table and case from the book • Results include plots of cross-section (to scale) bending moment, shear, stress, slope and deflection • Outputs to screen, printer or plotter.

Most importantly — you can solve problems forward or backward. For example: if the calculated deflection of a plate is too great, specify the maximum deflection you can tolerate. Then let the dimension of plate thickness become the unknown, and solve again. This backsolving feature is a designer's dream.

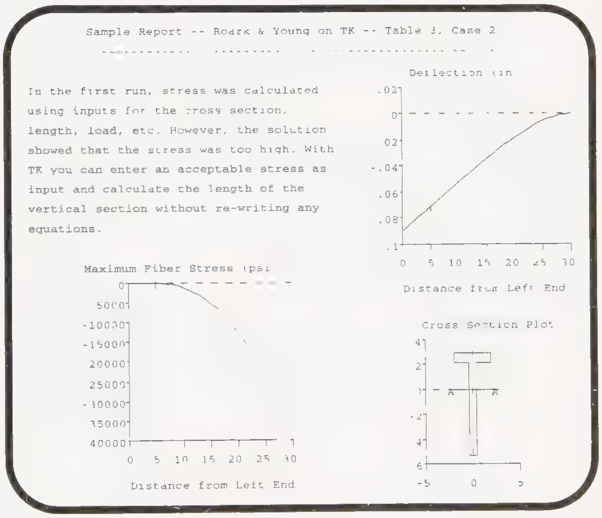
ROARK & YOUNG ON TK $1190

(For the IBM PC family or compatibles, 286 PC/MS Dos 3.2 or greater, 1 meg RAM)

(NOTE! The $1190 price includes TK Solver software (below) and a copy of the new 6th Edition.)

TK Solver 2.0 software . . . $595

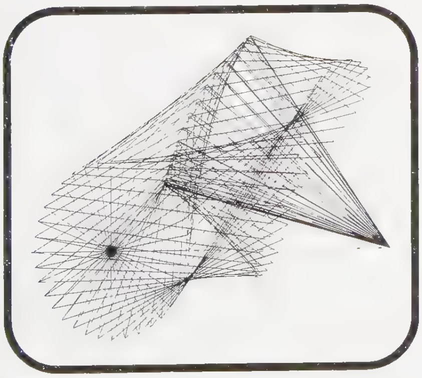
Solve dozens of linear, non-linear or differential equations simultaneously • backsolving lets you do "What-if" analysis • iterative solving • list solving • automatic plotting • automatic unit conversion • differentiation and integration • over 100 built-in functions and library routines • math co-processor support • presentation view lets you generate WYSIWYG reports • MathLook feature displays equations in near mathematical notation • keystroke macros with samples • link to many symbolic math packages.



Sample Report -- Roark & Young on TK -- Table 3, Case 2

In the first run, stress was calculated using inputs for the cross section, length, load, etc. However, the solution showed that the stress was too high. With TK you can enter an acceptable stress as input and calculate the length of the vertical section without re-writing any equations.

Deflection (in
.02
0
.02
-.04
.06
.08
.1
0
5
10
15
20
25
30
Distance from Left End
Maximum Fiber Stress (psi
0
5000
-10000
-15000
20000
25000
-30000
35000
40000
0
5
10
15
20
25
30
Distance from Left End
Cross Section Plot
4
2
1
A
A
-2
4
6
-5
0
5



SPECIAL OFFER!

If you order Roark & Young on TK, or TK Solver before July 31, 1992 you'll receive FREE a copy of Graphics 2000 Software — a $395 value!

When two-dimensional plots aren't enough, you can use Graphics 2000 software for precision 3D graphics and display. Visualize and present data, rotate about any axis, add light sources, modify numeric values or manipulate your results graphically. Smooth links with TK let you update your entire problem and display the results immediately in high-resolution 3D.

SATISFACTION GUARANTEED

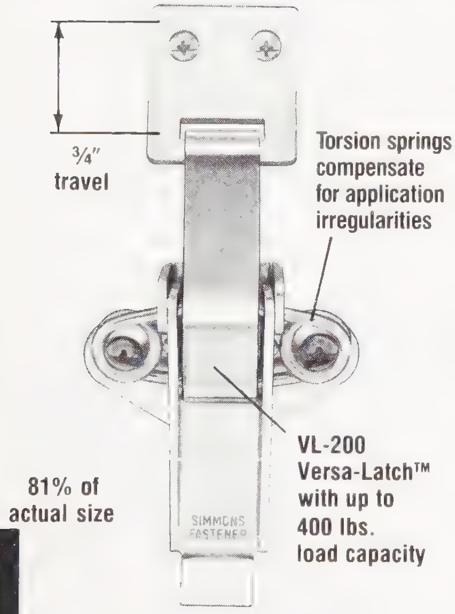
Use these programs on your PC. If they don't perform as described, just return the packages within 30 days for full credit or refund.

PENTON EDUCATION DIVISION
1100 Superior Avenue
Cleveland, Ohio 44114

Toll-free 800-321-7003 (in Ohio 216/696-7000)
FAX 216-696-4369

SIMMONS FASTENING TIPS

DRAW IT UP TIGHT WITH SIMMONS VERSA LATCH™!


3/4" travel
Torsion springs compensate for application irregularities
VL-200 Versa-Latch™ with up to 400 lbs. load capacity
81% of actual size
SIMMONS FASTENER

• Torsion springs compensate up to 3/32" for mounting irregularities or gasket set while maintaining constant latching pressure • Available in 100% stainless steel, or zinc plated carbon steel • Padlockable or wire sealed options available for extra security • Low profile • Also available: rugged VL-800 with 1/2" travel, up to 800 lbs. load capacity, and a mounting plate that provides an additional 1/8" adjustment • STL-250, another choice, combines good looks with approximately 5/32" travel and up to 250 lbs. load capacity • For more information, phone, fax or circle the reader service number.

Simmons Fastener
1750 North Broadway, P.O. Box 1985
Albany, New York 12201
TEL: 518-463-4234 • FAX: 518-463-0360

SIMMONS™

Circle 348

ditional take-up feature that can be used to compress the panel tightly against a frame member or sealing gasket. The draw-pull catch is used where panel movement is along the line of engagement, while the slide-action fastener is used to resist panel movement perpendicular to it. When all components are externally mounted, this fastener also meets the requirements for control boxes.

Push-pull: This fastener usually consists of an actuating button or knob linked to a locking device on the opposite side of the panel. The locking device may engage a receiver component on the frame member, a hole in the frame member, a lip of the frame, or a shaped striker. The latching action is usually accomplished by pressure engagement, pushing either upon the panel or the latch button.

Variations of these fasteners are numerous, but use the following combinations of manual operations: push to lock - push to release; lock on closing - push to release; push to lock - pull to release; and pull to lock - pull to release.

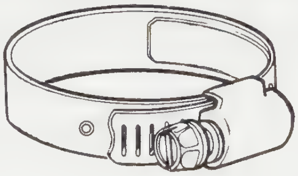
TYPES OF WORM-DRIVE CLAMPS

Worm-drive clamps are used to seal fluid or air connections on hoses. When the clamp screw is turned, the screw threads engage the notches in the band. This pulls the band through the housing, reducing the clamp diameter and squeezing the component together to seal the connection.

Clamps are typically made of 200, 300, or 400-grade stainless steel. The 300 grade provides maximum corrosion resistance because of its high nickel content and is usually specified for inground, marine, and other corrosive environments.

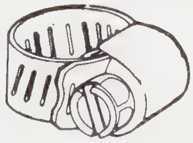
LINED CLAMP

Stainless-steel liner prevents hose extrusion and shearing through the band notches. This clamp is recommended for use on silicone-rubber hose and other applications where clamped surface must be protected.



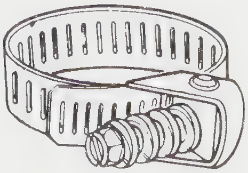
MINIATURE

Miniature clamps are suitable for installations in confined areas and for small-diameter hose, pipe and tubing.



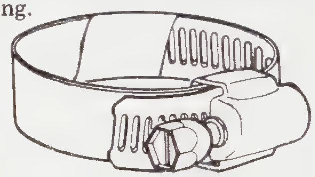
SWIVEL ACTION

Swivel-action clamp provides quick installation for "closed systems" where clamp must be opened to be applied.



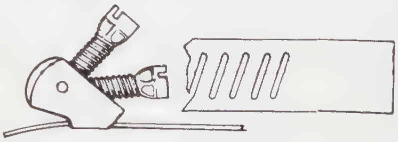
SAFETY COLLARED

Safety-collared screw provides slip-proof fastening. It is recommended for general service on hose pipe and tubing.



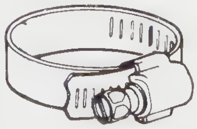
TWO PART

For permanent installations of the clamp with rivets or screws, two-part band lengths and clamp styles vary.



STANDARD

This clamp is recommended for general service on hose, pipe, and tubing.



The push-pull fasteners perform a basic latching function. Some play or clearance must be permitted between the attached panel and frame in the latched position, since these fasteners do not pull up or compress the panel to the frame or against a seal. The types requiring a receiver component or a hole in the frame will not tolerate much misalignment.

Push-pull fasteners are used where quick access without special tools is required and where space limitations or other factors make lift, turn, or slide action undesirable. They should be used on lightly loaded panels and where the panel is not intended to be clamped against a frame or gasket.

Lift-and-turn latches: These combine lever-actuated latches and turn-operated pawl-type fasteners. A rotatable threaded shaft is used with a radially projecting pawl that can be positioned along the shaft to accommodate panel thickness. The shaft and pawl move axially when the lever is lifted or depressed, causing the pawl to move to the inner edge of a frame member. The pawl is rotated from its engagement behind the frame by rotating the lever while it is raised.

Lift-and-turn latches have the wide adjustability and compression found in the turn-operated pawl-type fasteners, plus quick action, good grip, and styling variations of lever-actuated latches.

Lift-and-turn fasteners are selected where elongated levers instead of round knobs are better suited to the styling requirements of the application or where the better grip and mechanical advantages of levers allow tighter panel-to-frame compression. They are chosen for compression or sealing applications where quick fastener operation is desirable and because the lever position allows a quick visual check on the status of an application where a number of such latches are used together.

Such latches are available with raised handles or with "flush" handles that lie close to the panel. Flush latches are operated by pushing in at one end of the lever, grasping the other end, and turning. Keylock styles are also available.

Magnetic catches: A magnetic catch is basically a magnetic core piece sandwiched between the two steel pole pieces. The magnet and its pole pieces are contained within a plastic or nonferrous housing that also provides a way to install or attach the magnetic catch. A small flat steel plate or "armature" is also provided and is installed on the mating component of the closure. The holding force does not usually exceed 15 lb, and 4 to 10 lb is very common.

Magnetic catches provide quick access where the forces required to keep the door closed are low, and a positive mechanical door-to-frame connection is not required for safety. The outer door or panel surface does not need to show any evidence of fastener attachment, and if an edge is accessible to pull upon, no other knob or finger hold is needed.

Magnetic catches have no moving parts to wear out, and are usually reliable, trouble free, and little affected by normal environments. The only maintenance required is to occasionally wipe off the contacting surfaces. Installation is quick and economical.

Spring-loaded devices: Spring-loaded plungers provide end forces for purposes of detent or holding parts in place. The body of such a plunger looks like a threaded insert, and plunger bodies come in a variety of thread sizes and with various locking devices, as do inserts. However, the body contains a spring and a plunger or ball.

TAKE A QUARTER-TURN AND YOU'RE HOME.

Your fastener requirements continuously change, and the demands placed upon your product designs are never ending. We at Paneloc understand that, and we're here to help. Our engineering and production personnel have the technical and practical experience necessary to assure that the product you get is the product you need.

Our vast array of quarter-turn fasteners combines the exceptional versatility, strength, light weight, ease of installation, reliability, vibration-proof locking, and cost effectiveness that you have been demanding. For applications from avionics to aerospace to instrumentation. Miniloc, Versaloc, Rotary Latch, High Performance, and Spring Latch fasteners . . . only from Paneloc.

We understand your concerns. We've been listening. To find out how well, write or call today for a free product design brochure and samples. We're The Paneloc Corporation, 142 Brickyard Road, Farmington, CT 06032, (203) 677-6711.

PANELOC

. . . Your Fastening Connection

Circle 349

The spring force, which may range from a few ounces to tens of pounds, is transmitted to the plunger or ball. The plunger or ball presses against a flat surface on the mating part, or into an indentation or hole which provides further locking action.

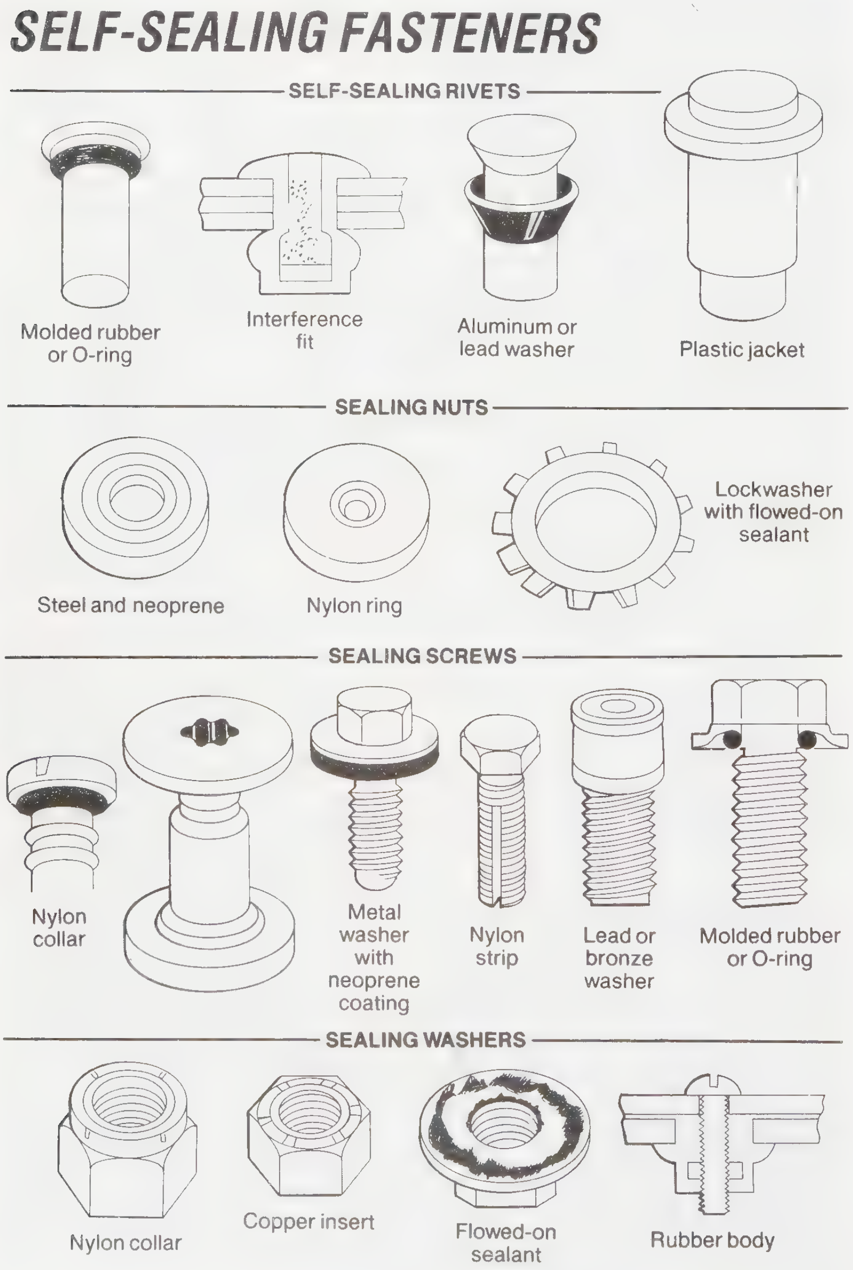
Plungers are available with various lengths of travel, and end force increases as the plunger is depressed. Ball plungers have very little travel, and provide a rolling action instead.

Advantages of spring-loaded plungers include quick operation and variable positioning. Such devices are available in a variety of materials for standard and special purposes, such as for use as electrical contacts.

Hose clamps

Hose clamps are made in a variety of types to match load, assembly, and cost specifications. Although there are many modifications within each type, the four major ones are worm-gear drive, latch, ear, and quick-connect straps.

Worm-gear metal hose clamps are available in different sizes for many load conditions. Most have a smooth internal face to avoid damage to hose surfaces. Latch clamps often have a ratchet tooth-locking action to retain clamping load. Typically used for light loads, the clamps are tightened in place with pliers.



Single-use ear clamps are usually applied in light-load situations. The clamp is slipped over a hose or duct and the ears are crimped with special tools.

Quick-connect straps are suitable for large-diameter ducts and light loads. The strap is pulled to a loose fit, then adjusted tighter by turning the screw.

Self-sealing fasteners

Fasteners also prevent gases and liquids from leaking. When large areas or mating surfaces must be sealed, a gasket or caulking compound is used. In this case, the fastener provides clamping force but contributes little to the sealing action. If the fastener hole must be sealed, or the fastener acts as a plug, a separate element or compound may be added to the fastener. Fasteners with preassembled, or built-in, seals include screws, rivets, nuts, and washers. Rubber, elastomers, plastic, soft metals, and interference fits are all used to maintain a seal.

Sealing element plays an important role in cost. Designers should be particularly aware of the amount of time the fastener will have to perform the sealing function. Often, a lower-cost sealing fastener is satisfactory if exposure to gas and liquid is not continuous.

Choosing a material depends largely on its ability to resist attack from the liquid or gas it is to seal. Common sealing materials are: Buna N, neoprenes, butyl rubber, silicones, natural rubber, fluoroethylene polymers, polyethylene, and nylons. The characteristics of these materials should be carefully matched to the design requirements.

Temperature can have beneficial and detrimental effects on the initial seal. In low-pressure applications, moderate temperatures sometimes improve the initial seal. Prolonged exposure to higher-than-ambient temperature causes many seal materials to harden. Abnormally high temperatures can cause a complete breakdown in the seal.

Pressure causes mastic sealers or soft elastomer sealing compounds to flow. They are not recommended for pressures above 100 psi. But, when properly supported, the soft material resists 2,000 psi. "Soft" sealing fasteners are not recommended for applications where surface quality varies.

Rubber and plastics can resist leakage in the full range of pressure from vacuum to more than 5,000 psi.

Corrosion is resisted by many formulations of rubbers and plastics. In several applications, stainless-steel fasteners are used with silicone or rubber, or fluorocarbons. ■

FASTENING, JOINING & ASSEMBLY

Write this number on the Reader Service Card to receive information from all advertisers making the listed products.

ASSEMBLY COMPONENTS

1539 Belleville springs
1540 Bolts
1541 Bushings
1542 Collars
1543 Dowels
1544 Eyelets
1545 Frictional shaft connectors
1546 Grommets
1547 Hinges, brackets
1548 Hose clamps
1549 Inserts
1550 Keys
1551 Latches, panel
1552 Latches, quick-operating
1553 Locking fasteners
1554 Locknuts
1555 Lockwashers
1556 Nuts
1557 Pins
1558 Retainers, cable & tube
1559 Retaining rings
1560 Rivets
1561 Rivets, blind
1562 Screws
1563 Setscrews
1564 Spacers
1565 Self-sealing fasteners
1566 Shaft hub connectors
1567 Shear bolts
1568 Spring clips
1569 Spring-loaded devices
1570 Standoffs
1571 Staples
1572 Stud receivers
1573 Studs
1574 Tolerance rings
1575 Vibration isolators, mounts, bumpers
1576 Washers
1577 Other

JOINING MATERIALS

1578 Adhesives
1579 Joining materials

JOINING PROCESSES

1580 Adhesive bonding & joining
1581 Fusion bonding
1582 Riveting
1583 Welding

ELECTRICAL AND ELECTRONIC SYSTEMS

Motors

Electrical drives

Input/output devices

Power supplies

Indicators and displays

Interconnections

A
Accelerometers 523
B
Batteries 562
Blowers 612
C
Cable ties 579
Cables 579
Circuit breakers 543
Connectors 593
Connectors, fiber-optic 598
Connectors, PCBs 593
Connectors, screw terminal . . . .
Contactors 545
Controllers, ac variable-speed 476
Controllers, dc variable-speed 477
Converters 483
D
Displays, CRTs 574
Displays, EL 572
Displays, Electrochromic 573
Displays, flat-panel 570
Displays, LCDs 571
Displays, plasma 573
Displays, raster 574
Drive selection 483
Dynamic braking 483
E
Eddy-current drives 477
Electronic gearing 492
Enclosure cooling 609
Enclosures 608
Encoders 495
Encoders, linear 495
Encoders, magnetic 498
Encoders, optical 503
F
Fans 612
Fiber optics 580
H
Heat sinks 610
I
ICs 530
ICs, power 537
ICs, high-voltage 561
Indicators 569
Indicators, miniature lamps 569
Indicators, neon lamps 569
Indicators, LEDs 569
K
Keyboards 541
L
LVDTs 503
Light filters 576
M
Mosfets 531
Motor protectors 443
Motor ratings 410
Motor selection 460
Motor starters 436
Motors, ac 414
Motors, ac capacitor 416
Motors, ac induction 416

Advertisers

AMP, Incorporated 581-59
Ametek, Incorporated 469,60
Anorad Corporation 44
BEI Motion Systems Company 53
Baldor . . . . B
Bayside Controls, Inc. 45
Bison Gear & Engineering
  Corporation 435,461-46
Burgess SAIA, Inc. 52
Carlon 599-60
Crouzet Corporation 52
Dynamics Research Corporation . . 499-50
Eagle Electric Mfg. Co., Inc. 53
Emerson & Cuming, A Grace Company . 57
Fuji Electric Corporation of America . . . 61
Graseby Volkmann 49
Harting Elektronik, Inc. 61
Hobbs Corporation 51
Hurst Manufacturing Division,
  Emerson Electric Company 44
Industrial Devices 485-48
Industrial Drives,
  A Kollmorgen Div. 445-44
Inertial Motors Corp. 44
Inland Motor, Kollmorgen
  Corp. . . .407,409,411,413,415,417,419,42
Mabuchi Motor America Corp. 44
MagneTek, Inc. 432-43

DIRECT-DRIVE DC TORQUE MOTORS FROM INLAND MOTOR

A direct-drive motor can be directly attached to the load it drives, thereby eliminating backlash and increasing servo stiffness. It is well suited to applications when a motor's size, weight, response time, and required power input must be minimized while its positional accuracy is maximized.

Inland Motor's design base of brush-type models includes both torque motors for slow-speed, precise-positioning applications, and servo motors for running applications where motor response time is critical. Many of our models incorporate rare-earth magnet materials (including neodymium-iron-boron) for greater torque output than comparable designs using magnets with a lower energy product.

Other features of our direct-drive motors include:

- Diameters from 1 inch to over 40 inches
- Torque outputs from 2.8 oz•in to 5000 lb•ft
- Maximum winding temperature of 155°C for standard designs; 200°C for specialized designs
- Designs that meet U.S. and European defense standards
- Custom designs

Inland Motor designs and manufactures components for precise motion control in defense, aerospace, medical, and industrial process-control applications. We routinely design and manufacture our products to meet all appropriate military, space, and aviation standards. Our facility is certified to MIL-Q-9858. Call us for more information. We'll help you select the right products for your application.

FOR APPLICATIONS ASSISTANCE, CALL
1-800-753-MOTOR

INLAND MOTOR
KOLLMORGEN CORPORATION

501 First Street, Radford, VA 24141
PH: 1-800-753-6686, FAX 703/731-4193

Circle 350

Motors, ac linear 422
Motors, ac timing 422
Motors, dc 452
Motors, dc brushless 457
Motors, dc compound 454
Motors, dc coreless 456
Motors, dc limited-angle 458
Motors, dc linear 468
Motors, definite & special-purpose 431
Motors, disc 476
Motors, gear 431
Motors, permanent-magnet 468
Motors, repulsion 420
Motors, series 452
Motors, servo 422
Motors, shaded-pole 418
Motors, shunt 452
Motors, stepping 470
Motors, universal 418

O

Op amps 539
Overcurrent protectors 443

P

Piezoelectric materials 523
Power ICs 537
Power supplies 549
Power supplies, operational 556
Power supplies, regulated 553

R

Relays 540
Relays, electromechanical 545
Relays, reed 545
Relays, solid-state 547
Resolvers 498

S

Semiconductors 530
Sensors 495
Sensors, magnetic 504
Sensors, pressure 519
Sensors, proximity 526
Sensors, temperature 510
Shielding 604
Starters 436
Strain gages 519
Surface mounts 603
Surge suppressors 555
Switch contacts 530
Switches 530
Switches, mechanical 543
Switches, membrane 541
Switches, temperature 514
Switches, touch 543
Synchros 498

T

Temperature sensors, RTDs 512
Temperature sensors, thermistors 512
Terminal blocks 591
Terminals 591
Thermal cutoffs (TCOs) 520
Thermocouples 511
Thermostats 514
Touch screens 575
Transducers 495
Transducers, electropneumatic 520
Transistors 530

V

Voltage regulators 558

W

Wiring, fiber optics 580
Wiring, flat cables 580
Wiring, ribbon cables 579

Mallory Controls 494
McLean Engineering 612
Merkle-Korff Industries 443
Micro Motors, Inc. 475
Namco Controls,
  An Acme-Cleveland Co. 513
Oriental Motor U.S.A. Corporation 437-440
Oven Industries, Inc.,
  Industrial Controls Division 536
Parker Seal 497
Penn Engineering & Manufacturing
  Corporation 607
Pepperl&Fuchs, Inc. 530
Pittman, A Division of Penn
  Engineering & Mfg. Corp. 453,455
Polyspede Electronics Corporation 491
Portescap U.S. Inc. 423-430
Potter & Brumfield Inc. 505-509
Renco Encoders, Inc. 537
Rittal Corporation 594-595
Rosemount Inc., Aerospace Division 525
SoMat Corporation 529
Stewart-Warner Hobbs Corporation 517
Superior Electric Co., The 456-457
Teledyne Gurley 521
Tempil 535
Transducer Techniques 536
Warner Electric/Dana Corp. 478-480

DIRECT DRIVE DC BRUSHLESS MOTORS FROM INLAND MOTOR

Brushless motor designs have expanded the performance capability of electromechanical drives. A brushless motor can operate over a broad range of speeds. Also, brush induced EMI/RFI is eliminated. The inside-out configuration of a brushless motor allows for better heat dissipation, lower rotor inertia, and faster response.

Brushless systems are well suited for special environments such as high altitudes or deep space, circulating fluids, explosive atmospheres, clean rooms, and vacuums.

Inland Motor designs and manufactures components for precise motion control in defense, aerospace, medical, and industrial process-control applications. We routinely design and manufacture our products to meet all appropriate military, space, and aviation standards. Our facility is certified to MIL-Q-9858. Call us for more information. We'll help you select the right products for your application.

Other capabilities include:

- Torque outputs from 3 oz•in to 35,000 lb•ft
- Speeds to 18,000 rpm for typical designs, and to 80,000 rpm for special designs
- Frameless or housed
- With or without commutation sensors
- Alnico, rare-earth, or ceramic magnet materials

FOR APPLICATIONS ASSISTANCE, CALL 1-800-753-MOTOR

INLAND MOTOR
KOLLMORGEN CORPORATION
501 First Street, Radford, VA 24141
PH: 1-800-753-6686, FAX 703/731-4193

Circle 351

Motors

Electric motors, both ac and dc types, come in many shapes and sizes. Some are standardized versions for general-purpose applications. Others are intended for specific tasks. In any case, motors should be selected to satisfy the dynamic requirements of the machines on which they are applied without exceeding rated motor temperature. Thus, the first, and most important, step in motor selection is determining load characteristics — torque and speed vs. time. Selection is also based on mission goals, power available, and cost.

Starting and running torque are the first parameters to consider when sizing a motor. Starting torque requirements can vary from a small percentage of full load to a value several times full-load torque. Starting torque varies because of a change in load conditions or the mechanical nature of the machine. The latter could be caused by the lubricant, wear of moving parts, or other reasons.

Motor torque supplied to the driven machine must be more than that required from start to full speed. The greater the reserve torque, the more rapid the acceleration.

Drive systems that use gear reducers have parts that rotate at different speeds. To calculate acceleration torque required for these systems, rotating components must be reduced to a common base. The part inertias are usually converted to their equivalent value at the drive shaft. Equivalent inertia $W_2K_2^2$ of the load only is found from:

$$W_2K_2^2 = (W_1K_1^2)(N_1/N_2)^2$$

where $W_1K_1{}^2$ = load inertia in lb-ft^2, N_1 = load speed in rpm, and N_2 = motor speed in rpm.

Bodies having straight-line motion are often connected to rotating driving units by rack-and-pinion, cable, or cam mechanisms. For these parts, the equivalent WK^2 is found from:

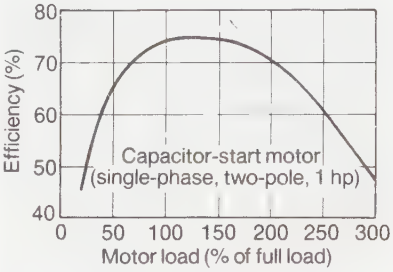
$$WK^2 = W(S/2\pi N)^2$$

where W = load weight, S = translation speed in fpm, and N = rotational speed in rpm.

Acceleration time: Acceleration time of a motor-driven machine is directly proportional to total inertia and inversely proportional to the torque. For motors with constant acceleration torque, acceleration time is:

$$t = \frac{WK^2(N_2 - N_1)}{308T_x}$$

where WK^2 = rotational inertia in lb-ft^2, $(N_2 - N_1)$ = the speed difference, and T_x = acceleration torque in lb-ft.



Motor efficiency is greatest near full load.

For translating bodies, acceleration time is:

$$t = \frac{W(S_2 - S_1)}{1.932F_x}$$

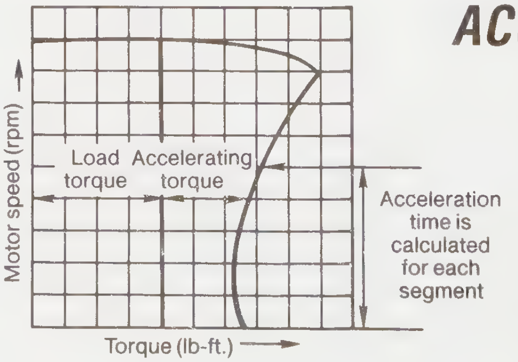
where W = weight of the load in lb, $(S_2 - S_1)$ = the translation speed difference, and F_x = translation force in lb.

An approximation method is necessary to find acceleration time if acceleration torque is not linear during speed increase. The quickest method is to break up the speed vs. torque curves of the driving unit and the driven machine into segments and calculate acceleration time for each segment. Accurate acceleration times usually result.

Power rating: The horsepower required to drive a machine is typically referred to as motor load. The most common equation for power based on torque and rotational speed is: hp = (torque × rpm)/5,250.

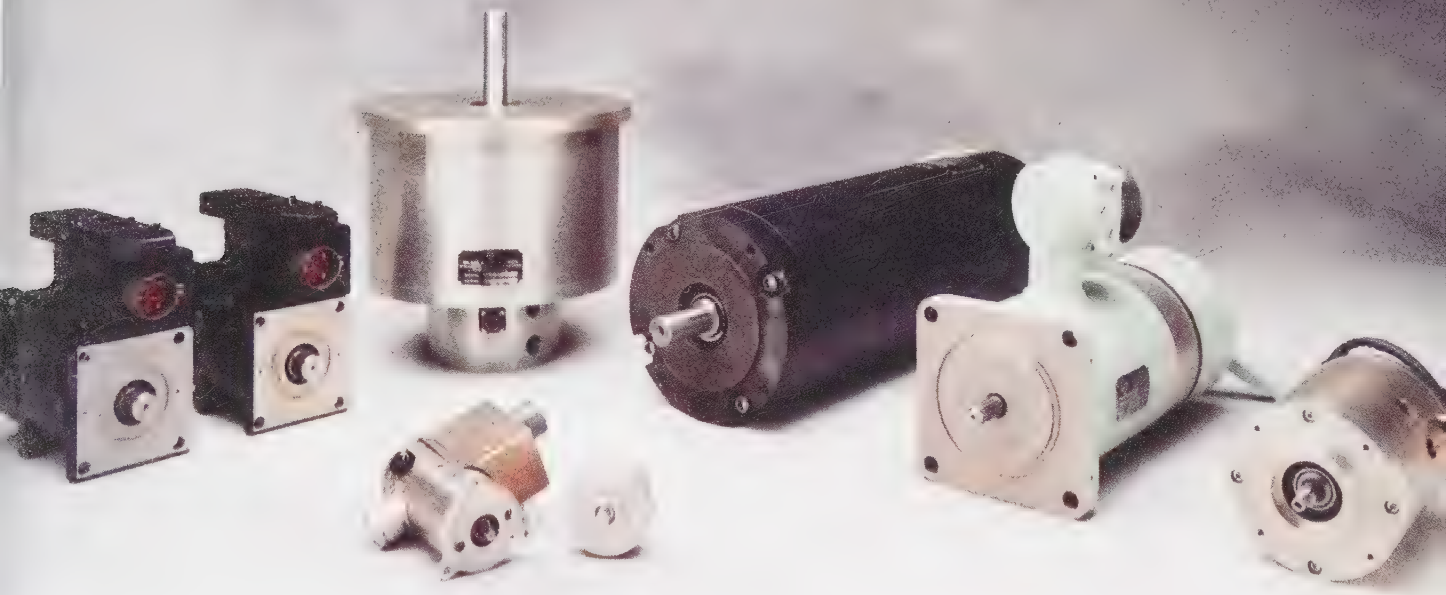
If load is not constant and follows a definite cycle, a horsepower vs. time curve for the driven machine is helpful. From this curve both peak and rms horsepower can be determined. Rms load horsepower indicates the necessary continuous motor rating. Peak load horsepower is not necessarily an indication of the required motor rating. However, when a peak load is maintained for a period of time, the motor rating usually should not be less than peak load horsepower.

Duty cycle: Continuous steady-running loads over long periods are demonstrated by fans and blowers. On the other hand, machines with flywheels may have wide variations in running loads. Often, the flywheel supplies the energy to do the work, and the motor does nothing but restore lost energy to the flywheel. Therefore, choosing the proper motor also depends on whether the load is steady, varies, follows a repetitive cycle of vari-



ACCELERATION

Acceleration time is approximated for motors with nonlinear acceleration torque by breaking the speed vs. torque curve into segments. Segment times are calculated and added together.



HOUSED AND ENVIRONMENTALLY SEALED MOTORS FROM INLAND MOTOR

We manufacture housed packages that can be tailored to meet customer requirements. Our housed designs have been used in diverse applications, from capstan drives for precision data recorders to turret drives for armored vehicles.

A housed motor can be designed as either brush-type or brushless. Package combinations can include integral tachometers, fail-safe electromagnetic brakes, resolvers, encoders, or EMI/RFI filtering to condition input signals. Other options include:

- Wound-field designs
- Wide range of output-shaft configurations
- Special connectors
- Totally enclosed, nonventilated construction for sealing against harsh environments such as water, salt, and sand

We also have extensive experience in manufacturing units to meet military specifications for extreme shock, vibration, and acceleration.

Inland Motor designs and manufactures components for precise motion control in defense, aerospace, medical, and industrial process-control applications. We routinely design and manufacture our products to meet all appropriate military, space, and aviation standards. Our facility is certified to MIL-Q-9858. Call us for more information. We'll help you select the right products for your application.

FOR APPLICATIONS ASSISTANCE, CALL
1-800-753-MOTOR

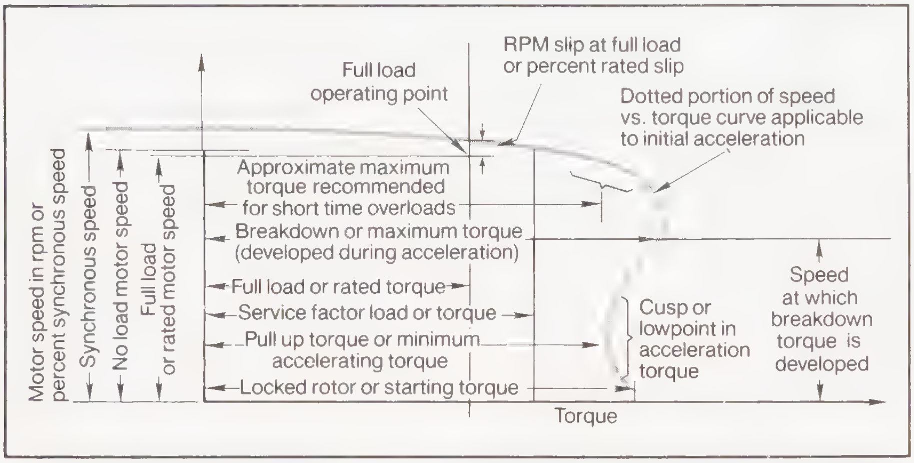
INLAND MOTOR
KOLLMORGEN CORPORATION
501 First Street, Radford, VA 24141
PH: 1-800-753-6686, FAX 703/731-4193

Circle 352

CHARACTERISTICS OF SPEED/TORQUE

The first step in sizing the motor is determining the power required to drive the machine. The next step is to examine motor performance curves to see if the motor has enough starting torque to overcome machine static friction, to accelerate the load to full running speed, and to handle maximum overload.

Basic information is contained in a speed vs. torque curve. The curve shown is for a general-purpose, squirrel-cage induction motor. It shows how output torque varies as speed increases from zero to synchronous speed with rated voltage and frequency applied to the motor.


Full load operating point
RPM slip at full load or percent rated slip
Dotted portion of speed vs. torque curve applicable to initial acceleration
Motor speed in rpm or percent synchronous speed
Synchronous speed
No load motor speed
Full load or rated motor speed
Approximate maximum torque recommended for short time overloads
Breakdown or maximum torque (developed during acceleration)
Full load or rated torque
Service factor load or torque
Pull up torque or minimum accelerating torque
Locked rotor or starting torque
Cusp or lowpoint in acceleration torque
Speed at which breakdown torque is developed
Torque

ation, or has pulsating torque or shocks.

For example, motors that run continuously in fans and blowers for hours or days may be selected on the basis of continuous load. But devices like automatically controlled compressors and pumps start a number of times per hour. And motors in some machine tools start and stop many times per minute.

Duty cycle is a fixed repetitive load pattern over a given period of time which is expressed as the ratio of on-time to cycle period. When operating cycle is such that the motor operates at idle or a reduced load for more than 25% of the time, duty cycle becomes a factor in sizing the motor. Also, energy required to start a motor (that is, accelerating the inertia of the motor as well as the driven load) is much higher than for steady-state operation, so frequent starting could overheat the motor.

For most motors (except squirrel-cage motors during acceleration and plugging) current is almost directly proportional to developed torque. At constant speed, torque is proportional to horsepower. For accelerating loads and overloads on motors that have considerable droop, use equivalent horsepower as the load factor.

The next step in sizing the motor is to examine motor performance curves to see if the motor has enough starting torque to overcome machine static friction, to accelerate the load to full running speed, and to handle maximum overload.

Service factors: A change in NEMA standards for service factors and temperature rise has been brought about because of better insulation. For instance, a 1.15 service factor — once standard for all open motors — is no longer standard above 200 hp.

Temperature rises are measured by the resistance method in the temperature rise table. Motor nameplate temperature rise is always expressed for the maximum allowable load. That is, if the motor has a service factor greater than unity, the nameplate temperature rise is expressed for the overload. Two Class-B insulated motors having 1.15 and 1.25 service factors will, therefore, each be rated for a 90°C rise. But the second motor will have to be larger than the first in order to dissipate the additional heat it generates at 125% load.

Service factor indicates how much over the nameplate rating a motor can be driven without overheating. NEMA Standard MGI-143 defines service factor of an ac motor as "...a multiplier which, when applied to the rated horsepower, indicates a permissible horsepower loading which may be carried under the conditions specified for the service factor..." In other words, multiplying nameplate horsepower by the service factor tells how much the motor can be overloaded without overheating.

Generally, service factors:

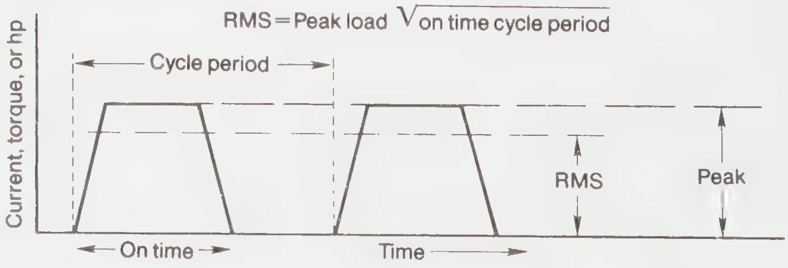
- Handle a known overload, which is occasional.
- Provide a factor of safety where the environment or service condition is not well defined, especially for general-purpose motors."
- Obtain cooler-than-normal motor operation at rated load, thus lengthening insulation life.

Motor efficiency: Small universal motors have an efficiency of about 30%, while 95% efficiencies are common for three-phase machines. In less-efficient motors, the amount of power wasted can be reduced by more careful application and improved motor design.

Motor efficiency also depends on ac-

CALCULATING DUTY CYCLE

Drive motors for variable duty-cycle loads usually have rated capacities less than peak load requirements. The root-mean-square method is the common technique for determining motor size for variable duty-cycle loads. Parameters such as horsepower, torque, or current can represent motor load.



Typical duty cycle curve. Curve shows a start-run-stop-idle cycle.

DYNAMIC RANGE DC TACHOMETERS FROM INLAND MOTOR

A dc tachometer measures motor speed and indicates rotational direction. A dc tachometer is used as a rate reference in rate servosystems and as a velocity damping device in position servosystems.

Tachometers are well suited for servosystems where size and weight must be minimized and high servo position resolution attained. A tachometer's simplicity of design and minimum of moving parts make it inherently reliable.

Other advantages are:

- High voltage gradient–the ratio of output voltage to rotational speed
- High linearity–the straight-line relationship of output voltage versus rotational speed
- Dynamic ranges up to 30,000:1
- Compact, adaptable design

We have tachometer designs for both military and industrial applications, as well as a wide range of sizes and mounting configurations.

Inland Motor designs and manufactures components for precise motion control in defense, aerospace, medical, and industrial process-control applications. We routinely design and manufacture our products to meet all appropriate military, space, and aviation standards. Our facility is certified to MIL-Q-9858. Call us for more information. We'll help you select the right products for your application.

FOR APPLICATIONS ASSISTANCE, CALL 1-800-753-MOTOR

INLAND MOTOR
KOLLMORGEN CORPORATION

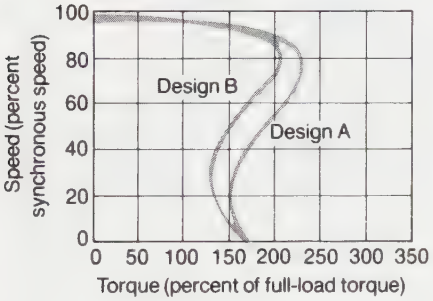
501 First Street, Radford, VA 24141
PH: 1-800-753-6686, FAX 703/731-4193

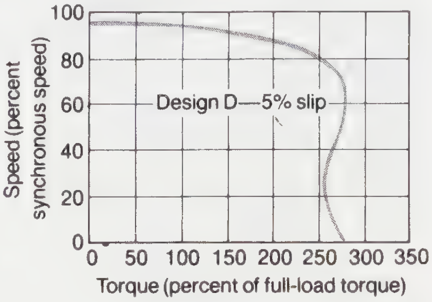
Circle 353

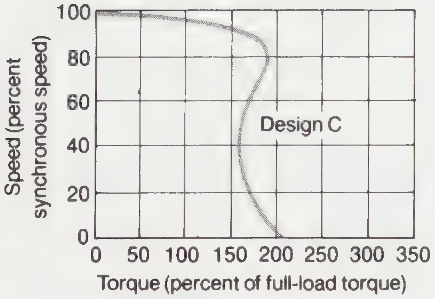
tual motor load vs. rated load, being greatest near rated load and falling off rapidly for under and overload conditions.

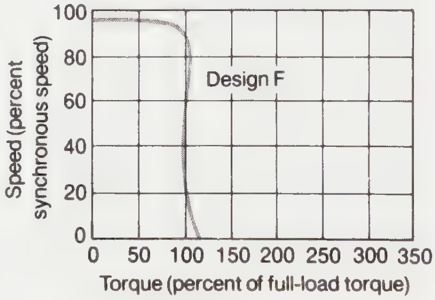
Ac motors

Asynchronous and synchronous motors are the two main categories of ac motors. The induction motor is a common form of asynchronous motor and is basically an ac transformer with a rotating secondary. The primary winding (stator) is connected to the power source and the shorted secondary (rotor) carries the induced secondary current. Torque is produced by the action of the rotor (secondary) currents on the air-gap flux. The synchronous motor differs greatly in design and operational characteristics, and is considered a separate class of motor.









For more information on motors described in this section, refer to the NEMA Standards Publication MG 1, "Motors and Generators."

Induction motors: Induction motors are the simplest and most rugged electric motor and consists of two basic electrical assemblies: the wound stator and the rotor assembly. The induction motor derives its name from currents flowing in the secondary member (rotor) that are induced by alternating currents flowing in the primary member (stator). The combined electromagnetic effects of the stator and rotor currents produce the force to create rotation.

Rotors typically consist of a laminated, cylindrical iron core with slots for receiving the conductors. The most common type of rotor has cast-aluminum conductors and short-circuiting end rings. This "squirrel cage" rotates when the moving magnetic field induces a current in the shorted conductors. The speed at which the magnetic field rotates is the synchronous speed of the motor and is determined by the number of poles in the stator and the frequency of the power supply: $n_s = 120f/p$, where n_s = synchronous speed, f = frequency, and p = the number of poles.

Synchronous speed is the absolute upper limit of motor speed. If the rotor turns exactly as fast as the rotating magnetic field, then no lines of force are cut by the rotor conductors, and torque is zero. When running, the rotor always rotates slower than the magnetic field. The rotor speed is just slow enough to cause the proper amount of rotor current to flow, so that the resulting torque is sufficient to overcome windage and friction losses, and drive the load. The speed difference between the rotor and magnetic field, called slip, is normally referred to as a percentage of synchronous speed: $s = 100 (n_s - n_a)/n_s$, where s = slip, n_s = synchronous speed, and n_a = actual speed.

Polyphase motors: Polyphase squirrel-cage motors are basically constant-speed machines, but some degree of flexibility in operating characteristics results from modifying the rotor slot design. These variations produce changes in torque, current, and full-load speed. Evolution and standardization have resulted in four fundamental types of motors.

Designs A and B: General-purpose motors with normal starting torques and currents, and low slip. Fractional-horsepower polyphase motors are generally design B. Because of the drooping characteristics of design B, a polyphase motor that produces the same breakdown (maximum) torque as a single-phase motor cannot attain the same speed-torque point for full-load speed as a single-phase motor. Therefore, breakdown torque must be higher (a minimum of 140% of the breakdown torque of a single-phase, general-purpose motor) so that full-load speeds are comparable.

Design C: High starting torque with normal starting current and low slip. This design is normally used where breakaway loads are high at starting, but which normally run at rated full load and are not subject to high overload demands after running speed has been reached.

Design D: High slip, very high starting torque, low starting current, and low full-load speed. Because of the high slip, speed can drop when fluctuating loads are encountered. This design is subdivided into several groups that vary according to slip or the shape of the speed-torque curve.

Design F: Low starting torque, low starting current, and low slip. This design is built to obtain low locked-rotor current. Both locked-rotor and breakdown torque are low. Normally used where starting torque is low and where high overloads are not imposed after running speed is reached.

Wound-rotor motors: Squirrel-cage motors are relatively inflexible with regard to speed and torque characteristics, but a special wound-rotor version has controllable speed and torque. Application of wound-rotor motors is markedly different from squirrel-cage motors because of the accessibility of the rotor circuit. Performance characteristics are obtained by inserting different values of resistance in the rotor circuit.

Wound-rotor motors are generally started with secondary resistance in the rotor circuit. The resistance is sequentially reduced to permit the motor to come up to speed. Thus, the motor can develop substantial torque while limiting locked-rotor current. This secondary resistance can be designed for continuous service to dissipate heat produced by continuous operation at reduced speed, frequent acceleration, or acceleration with a large inertia load. External resistance gives the motor a

DRIVE AND CONTROL ELECTRONICS FROM INLAND MOTOR

A servoamplifier is an essential component for system speed and torque control. It controls the power delivered to a motor and provides closed-loop operation for precise motion control.

A brushless servoamplifier contains additional circuitry to commutate the motor. It relies on rotor-position information from sensing devices such as Hall-effect sensors, resolvers, or encoders.

We offer a wide range of drives which have been designed to optimize the performance of our brush-type and brushless motors.

Inland Motor designs and manufactures components for precise motion control in defense, aerospace, medical, and industrial process-control applications. We routinely design and manufacture our products to meet all appropriate military, space, and aviation standards. Our facility is certified to MIL-Q-9858. Call us for more information. We'll help you select the right products for your application.

- Designs for military or commercial application
- Servocontrollers for brush-type or brushless motors
- Output power from 30 to 12,000 watts
- Linear and PWM designs
- Sine-wave or six-step commutation for brushless motor controllers
- Modular or rack-mount packaging; some designs also have optional back mounting
- Wide-band current-loop operation

FOR APPLICATIONS ASSISTANCE, CALL 1-800-753-MOTOR

INLAND MOTOR
KOLLMORGEN CORPORATION

501 First Street, Radford, VA 24141
PH: 1-800-753-6686, FAX 703/731-4193

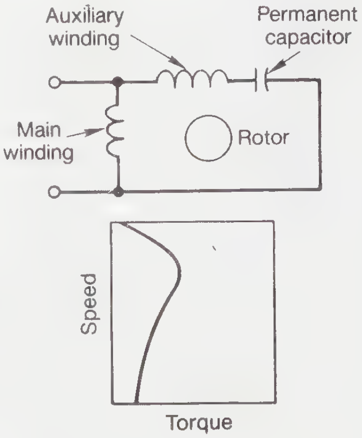
Circle 354

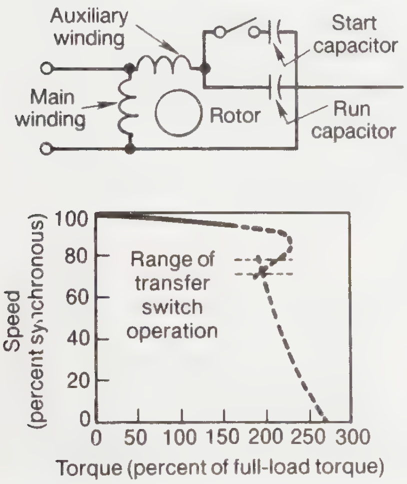
SINGLE-PHASE CAPACITOR MOTORS

Induction motors sometimes use capacitors in their armature circuits to produce starting and running torques. The three types include permanent split-capacitor, capacitor-start, and two-value capacitor.

PERMANENT SPLIT-CAPACITOR

This motor also has an auxiliary winding with a capacitor. But the capacitor and auxiliary windings are continuously energized and aid in producing a higher power factor than other designs. Efficiency is comparable to, and can be more than, the efficiency of other single-phase designs, but locked-rotor torque is low. Permanent split-capacitor motors are normally used only for direct-drive fan and blower applications and are not recommended for belt-driven loads. No centrifugal switch is needed, so the motor is usually shorter than other designs. Since both windings are always energized, these motors lend themselves to speed control (by voltage control) for variable torque (fan) applications.




Auxiliary winding
Start capacitor
Main winding
Rotor
Run capacitor
Speed (percent synchronous)
100
80
60
40
20
0
Range of transfer switch operation
0
50
100
150
200
250
300
Torque (percent of full-load torque)

TWO-VALUE CAPACITOR

The run capacitor and auxiliary winding are permanently connected in parallel with the main winding. In addition, a starting capacitor and a centrifugal switch are also in parallel with the run capacitor. The switch disconnects the starting capacitor as the motor accelerates.

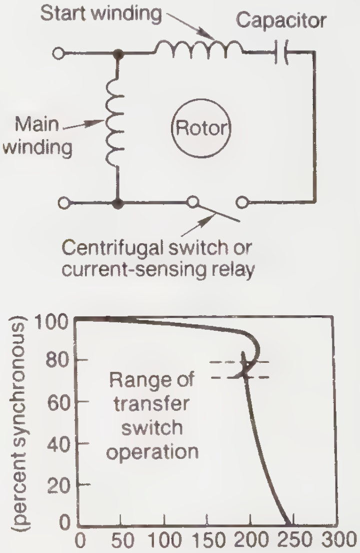
Also known as capacitor-start, capacitor-run motors, they have high torques during start and acceleration. The presence of the run capacitor improves the power factor, efficiency, and torque pulsations.

These motors are exceptionally quiet and available in fractional horsepower to 20-hp ratings.

CAPACITOR-START

The main difference between these motors and split-phase motors is that a capacitor is placed in series with the auxiliary winding. This motor produces greater locked-rotor and accelerating torque per ampere than does the split-phase motor. Thus, capacitor-start motors should be used where required load-acceleration and locked-rotor torques exceed the capacity of a split-phase motor. After the start winding is removed from the circuit, performance is identical to split-phase motors.

Having a higher starting torque than the split-phase type, this motor is useful for applications requiring more torque, such as air compressors and pumps. Sizes range to 7¼ hp. Integral-horsepower versions are made in sizes up to 10 hp at speeds from 900 to 3,600 rpm.



---

characteristic that results in a large drop in rpm for a fairly small change in load. Reduced speed is provided down to about 50% rated speed, but efficiency is low.

Multispeed motors: Consequent-pole motors are designed for one speed. By physically reconnecting the leads, a 2:1 speed ratio can be obtained. Typical synchronous speeds for a 60-Hz motor are: 3,600/1,800 rpm (2/4 pole), 1,800/900 rpm (4/8 pole), and 1,200/600 rpm (6/12 pole).

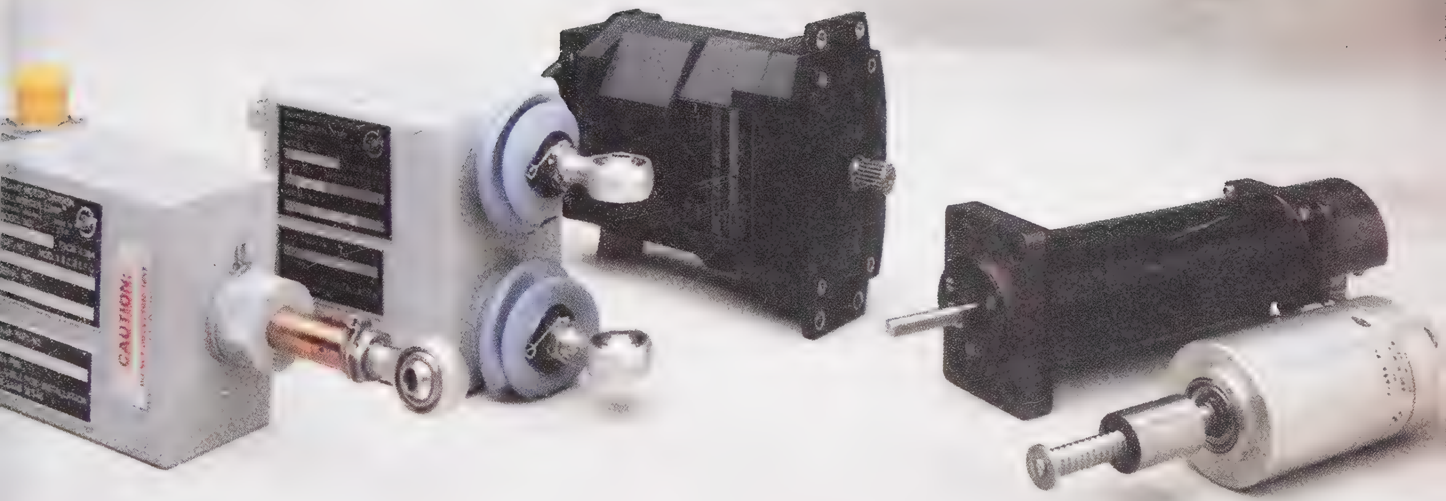
Two-winding motors have two separate windings that can be wound for any number of poles so that other speed ratios can be obtained. However, ratios greater than 4:1 are impractical because of motor size and weight. Single-phase multispeed motors are usually variable-torque design, but constant-torque and constant-horsepower motors are available.

Power output of multispeed motors can be proportioned to each different speed. These motors are designed with output horsepower capacity in accordance with one of the following load characteristics.

Variable torque: Motors have a speed torque characteristic that varies as the square of the speed. For example, an 1,800/900-rpm motor that develops 10 hp at 1,800 rpm produces 2.5 hp at 900 rpm. Since some loads, such as centrifugal pumps, fans, and blowers, have a torque requirement that varies as the square or cube of the speed, this motor characteristic is usually adequate.

Constant torque: These motors can develop the same torque at each speed, thus power output varies directly with speed. For example, a motor rated at 10 hp at 1,800 rpm produces 5 hp at 900 rpm. These motors are used in applications with constant torque requirements such as mixers, conveyors, and compressors.

Constant horsepower: These motors develop the same horsepower at



ELECTROMECHANICAL ACTUATORS FROM INLAND MOTOR

Inland Motor supplies actuators for a variety of aviation and aerospace applications, from military and commercial aircraft to modern missile systems. We have extensive experience in secondary flight-control actuators for commuter aircraft. We integrate the motor, control electronics, and mechanics in house to produce electromechanical actuators that achieve minimum size and weight. Our EMA systems include:

- Linear actuators from 200 lb to 50,000 lb thrust
- Rotary actuators from 320 oz•in to 75 lb•ft torque
- EMA units incorporating ac motors, as well as brush-type and brushless dc motors

Inland Motor has been at the forefront of electrical actuation for aircraft and missiles since the late seventies. We are now manufacturing pitch, roll, and yaw trim actuators for commuter aircraft.

Inland Motor designs and manufactures components for precise motion control in defense, aerospace, medical, and industrial process-control applications. We routinely design and manufacture our products to meet all appropriate military, space, and aviation standards. Our facility is certified to MIL-Q-9858. Call us for more information. We'll help you select the right products for your application.

FOR APPLICATIONS ASSISTANCE, CALL
1-800-753-MOTOR

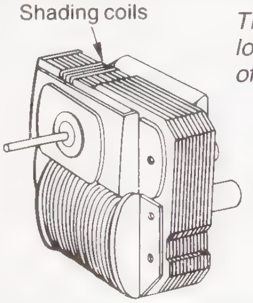
INLAND MOTOR
KOLLMORGEN CORPORATION
501 First Street, Radford, VA 24141
PH: 1-800-753-6686, FAX 703/731-4193

Circle 355

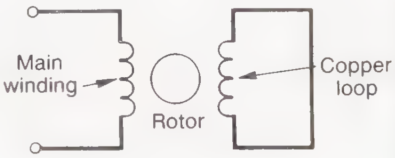
SINGLE-PHASE, SHADED-POLE MOTORS

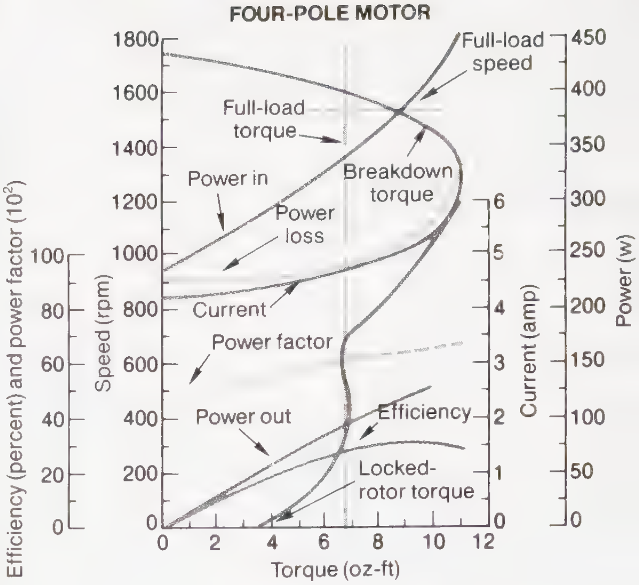
Shaded-pole motors have a continuous solid-copper loop around a small portion of each salient pole. This shading coil causes the necessary reaction to give the motor its starting torque. The coil produces only moderate torque during acceleration and running. Applications are principally in light-duty appliances because of low efficiency, power factor, and starting torque. Motors are suitable for direct-drive fan and blower applications. Air cooling is almost always required. Enclosed versions are possible in the smaller ratings (⅛ hp and lower), or where cooling effect of the air stream is exceptionally good. Shaded-pole motors with four and six poles (1,550 and 1,050 rpm) are most common.

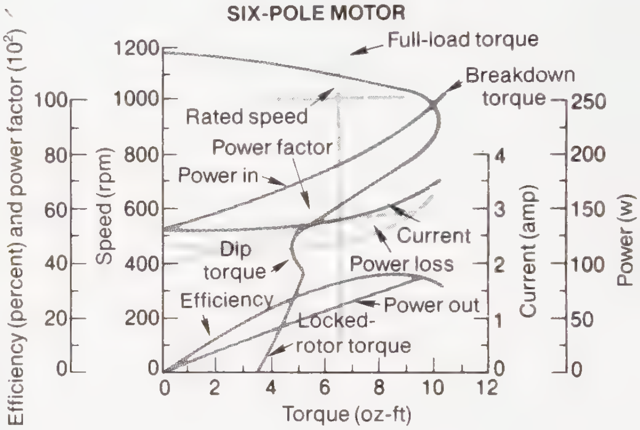
Primarily for low-torque applications, such as in small fans, these motors are available in subfractional to fractional horsepower sizes.



The shaded-pole motor is usually the lowest priced induction motor because of its simple mechanical construction.




FOUR-POLE MOTOR


SIX-POLE MOTOR

each speed and the torque is inversely proportional to the speed. Typical applications include machine tools such as drills, lathes, and milling machines.

Single-phase motors: Single-phase induction motors are commonly fractional-horsepower types, although single-phase integral-horsepower are available in the lower horsepower range. The most common fractional-horsepower single-phase motors are split-phase, capacitor-start, permanent split-capacitor, and shaded pole.

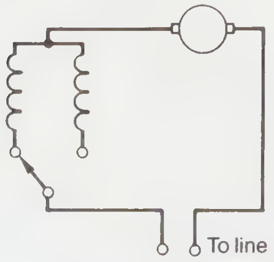
The motors come in multispeed types, but there is a practical limit to the number of speeds obtained. Two, three, and four-speed motors are available, and speed selection may be accomplished by consequent-pole or two-winding methods.

Single-phase motors run in the direction in which they are started; and they are started in a predetermined direction according to the electrical connections or mechanical setting of the starting means. General-purpose motors may be operated in either direction, but the standard rotation is counterclockwise when facing the end opposite the drive shaft. Motors can be reconnected to reverse the direction of rotation.

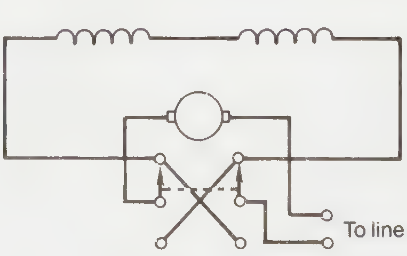
Universal motors: The universal motor operates with nearly equivalent performance on direct current or alternating current up to 60 Hz. It differs from a dc series motor because of winding ratios and thinner iron laminations. A dc series motor runs on ac, but with poor efficiency. A universal motor can operate on dc with essentially equiv-

REVERSING UNIVERSAL MOTORS

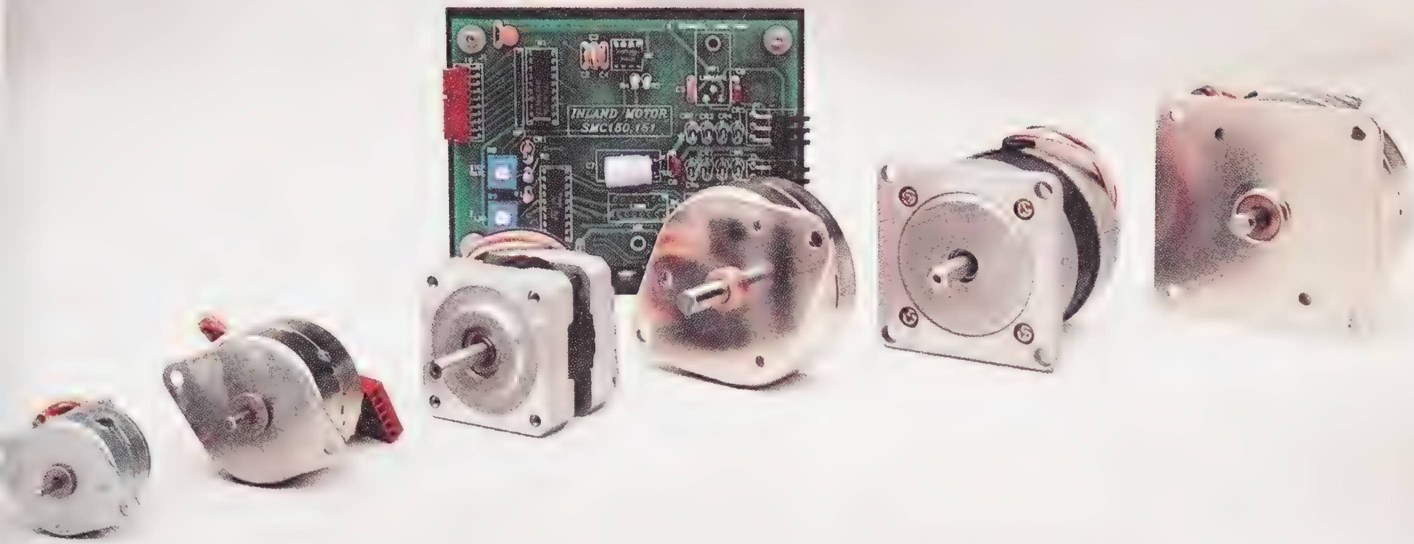
Field coils are connected together, with the armature between one side of the line and the field, for reversible motors. Either three or four leads are supplied. The three-lead motor requires only a single-pole, double-throw (spdt) switch. However, for this arrangement, a double field winding is required. Another common practice is to use the coil of one pole for one direction of rotation and the other coil for opposite rotation. A four-wire reversible motor requires a dpdt switch.



THREE-LEAD SPDT



FOUR-LEAD DPDT



HIGH PERFORMANCE STEP MOTORS AND CONTROLS FROM INLAND MOTOR

Inland Motor offers both permanent-magnet and hybrid step motors and matched controllers, with motor torque outputs from 1 to 100 oz•in. Ideal for high-volume, mass-production applications, step motors may be specified with a variety of flanges and shafts. Both canned stack and hybrid step motors are available. Hybrid models are well suited for applications that require high torque and superior response characteristics.

Chip-level and board-level controls, including micro-stepping controls, are available. Some board-level controls are self-contained multiple-axis units with built-in memory and programmable input/output.

Inland Motor designs and manufactures components for precise motion control in defense, aerospace, medical, and industrial process-control applications. We routinely design and manufacture our products to meet all appropriate military, space, and aviation standards. Our facility is certified to MIL-Q-9858. Call us for more information. We'll help you select the right products for your application.

FOR APPLICATIONS ASSISTANCE, CALL
1-800-753-MOTOR

INLAND MOTOR
KOLLMORGEN CORPORATION
501 First Street, Radford, VA 24141
PH: 1-800-753-6686, FAX 703/731-4193

Circle 356

alent ac performance, but with poorer commutation and brush life than for an equivalent dc series motor.

An important characteristic of a universal motor is that it has the highest horsepower-per-pound ratio of any ac motor because it can operate at speeds many times higher than that of any other 60-Hz motor.

When operated without load, a universal motor tends to run away, speed being limited only by windage, friction, and commutation. Therefore, large universal motors are nearly always connected directly to a load to limit speed. On portable tools such as electric saws, the load imposed by the gears, bearings, and cooling fan is sufficient to hold the no-load speed down to a safe value.

With a universal motor, speed control is simple, since motor speed is sensitive to both voltage and flux changes. With a rheostat or adjustable autotransformer, motor speed can be readily varied from top speed to zero.

Synchronous motors: Synchronous motors are inherently constant-speed motors and they operate in absolute synchronism with line frequency. As with squirrel-cage induction motors, speed is determined by the number of pairs of poles and is always a ratio of the line frequency.

Synchronous motors are made in sizes ranging from subfractional self-excited units to large-horsepower, direct-current-excited motors for industrial drives. In the fractional-horsepower range, synchronous motors are used primarily where precise constant speed is required.

In large horsepower sizes applied to industrial loads, synchronous motors serve two important functions. First, it is a highly efficient means of converting ac energy to mechanical power. Second, it can operate at leading or unity power factor, thereby providing power-factor correction.

There are two major types of synchronous motors: nonexcited and direct-current excited.

Nonexcited motors are made in reluctance and hysteresis designs. These motors employ a self-starting circuit and require nò external excitation supply.

Dc-excited motors come in sizes larger than 1 hp, and require direct current supplied through slip rings for excitation. Direct current may be supplied from a separate source or from a dc generator directly connected to the motor shaft.

Single-phase or polyphase synchronous motors can't start without being driven, or having their rotor connected in the form of a self-starting circuit. Since the field is rotating at synchronous speed, the motor must be accelerated before it can pull into synchronism. Accelerating from zero speed requires slip until synchronism is reached. Therefore, separate starting means must be employed.

In self-starting designs, fhp sizes use starting methods common to induction motors (split-phase, capacitor-start, repulsion-start, and shaded-pole). The electrical characteristics of these motors cause them to automatically switch to synchronous operation.

Although the dc-excited motor has a squirrel cage for starting, called an amortisseur or damper winding, the inherent low starting torque and the need for a dc power source requires a starting system that provides full motor protection while starting, applies dc field excitation at the proper time, removes field excitation at rotor pull out (maximum torque), and protects the squirrel-cage winding against thermal damage under out-of-step conditions.

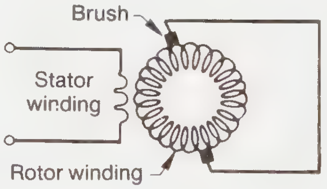
Pull-up torque is the minimum torque developed from standstill to the pull-in point. This torque must exceed load torque by a sufficient margin so that a satisfactory rate of acceleration is maintained under normal voltage conditions.

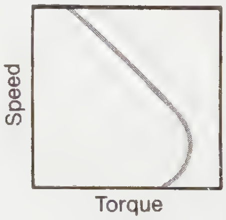
Reluctance torque results from the saliency (preferred direction of magnetization) of the rotor pole pieces and pulsates at speeds below synchronous. It also has an influence on motor pull-in and pull-out torques because the un-

REPULSION MOTORS

These motors consist of an armature winding, a commutator, and brushes. Brushes are short-circuited and shifted to give the effect of two stator windings: a field winding at right angles to the brush axis, and an induction winding along the brush axis. This induction winding induces current in the armature winding that reacts with the field set up by the field winding, thus producing torque. These motors have good starting characteristics and are used for heavy loads.

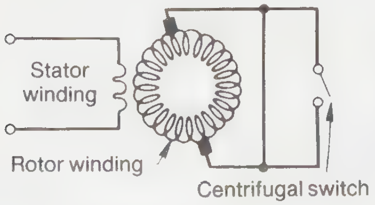
Repulsion motors are not used much today. Most applications use repulsion-start and repulsion-induction motors.

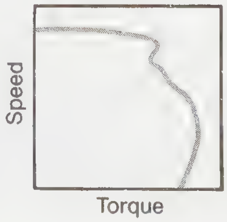




REPULSION-START MOTORS

Repulsion-start motors are the most popular commutator, single-phase motors for industrial applications. A centrifugal switch is included. At about 75% of synchronous speed, the switch short-circuits the commutator bars, and the motor simulates a squirrel-cage motor at full speed.

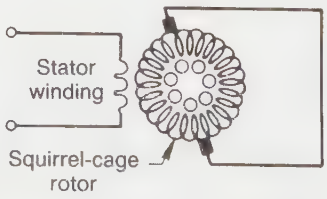


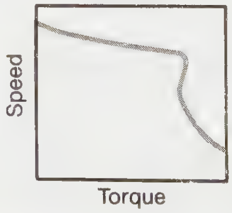


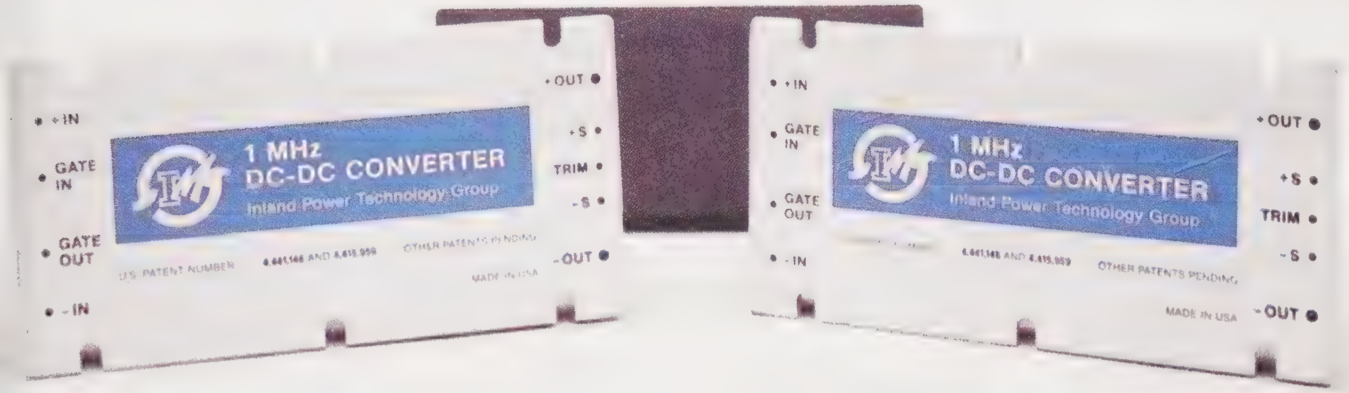
REPULSION-INDUCTION MOTORS

These motors are similar to repulsion motors, except a squirrel-cage winding is added. The cage improves speed regulation and eliminates the need for a centrifugal switch.

The motor is used for applications requiring starting under full load, such as in conveyors and stokers.







DC/DC CONVERTERS FROM INLAND MOTOR

Inland Motor designs and manufactures high frequency dc/dc converters in packages for ground-based, mobile, shipboard, and airborne applications. Mil-spec manufacturing, quality control, component selection, and derating assure consistent performance and reliability. These models incorporate short-circuit protection and operate over a baseplate temperature range of -55 to +85°C. The output of each unit can be augmented with power boosters.

Inland Motor designs and manufactures components for precise motion control in defense, aerospace, medical, and industrial process-control applications. We routinely design and manufacture our products to meet all appropriate military, space, and aviation standards. Our facility is certified to MIL-Q-9858. Call us for more information. We'll help you select the right products for your application.

FOR APPLICATIONS ASSISTANCE, CALL
1-800-753-MOTOR

INLAND MOTOR
KOLLMORGEN CORPORATION

501 First Street, Radford, VA 24141
PH: 1-800-753-6686, FAX 703/731-4193

Circle 357

AC TIMING MOTORS

Inductor motors are similar to hysteresis motors, except they use a permanent magnet for a rotor. The number of poles determines the rotational speed. Because the rotor poles are permanent, the rotor must accelerate very rapidly to follow the stator field.

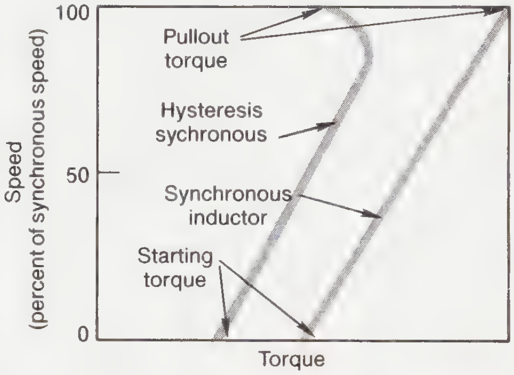
Advantages include fast starts and stops, accurate speed, and high efficiency. Fast starts and stops are caused by the detent action of the rotating field and the permanent magnet. This effect is so strong that these motors can also be used as stepper motors. Speed accuracy is as good as line frequency. Since only one field needs to be energized (the permanent magnet supplies the other field), efficiency is high.

Disadvantages include low starting torque (50% of running torque), and large speed variation. Applications include chart drives, printer drives, ribbon drives, and pumps.

Synchronous hysteresis motors are designed for unidirectional or bidirectional operation. Bidirectional designs have two phases, and during operation one phase leads the other by 90°. This is done with a capacitor. The direction of rotation depends on which phase is energized through the capacitor.

Unidirectional designs have only a single phase, and could rotate in either direction. A shading ring is used to cancel unwanted fields, thus preventing rotation in the wrong direction.

Compared to an inductor motor, a hysteresis motor provides higher starting torque and lower speed variation. But efficiency is lower and damping is poor. Hysteresis motors are suited for low-cost applications such as clock drives.



excited salient-pole rotor tends to align itself with the stator magnetic field to maintain minimum magnetic reluctance. This reluctance torque may be sufficient to pull into synchronism a lightly loaded, low-inertia system and to develop approximately a 30% pull-out torque.

Synchronous torque is torque developed after excitation is applied, and represents the total steady-state torque available to drive the load. It reaches maximum at approximately 70° lag of the rotor behind the rotating stator magnetic field. This maximum value is actually the pull-out torque.

Pull-out torque is the maximum sustained torque the motor develops at synchronous speed for one minute with rated frequency and normal excitation. Normal pull-out torque is usually 150% of full-load torque for unity-power-factor motors, and 175 to 200% for 0.8-leading-power-factor motors.

Pull-in torque of a synchronous motor is the torque that it develops when pulling its connected inertia load into synchronism upon application of excitation. Pull-in torque is developed during transition from slip speed to synchronous speed, as the motor changes from induction to synchronous operation. It is usually the most critical period in starting a synchronous motor. Torques developed by the amortisseur and field windings become zero at synchronous speed. At the pull-in point, therefore, only the reluctance torque and the synchronizing torque provided by exciting the field windings are effective.

Timing motors: Timing motors are rated under $\frac{1}{10}$ hp and are used as prime movers for timing devices. Since the motor is being used as a timer, it must run at constant speed. Speed is held constant because of the way the motor is constructed, or a governor is used.

Ac and dc motors can be used as timing motors. Dc timing motors are used for portable applications, or where high acceleration and low speed variations are required. Advantages include starting torque as high as ten times running torque, efficiency from 50 to 70%, and relatively easy speed control. But some form of speed governor, either mechanical or electronic, is required.

Ac motors use readily available power, are lower in cost, have improved life, and do not generate RFI. However, ac motors ca not be readily adapted to portable applications, have relatively low starting torques, and are much less efficient than dc motors.

Ac servomotors: Ac servomotors are used in ac servomechanisms and computers which require rapid and accurate response characteristics. To achieve these characteristics, servomotors have small-diameter high-resistance rotors. The small diameter provides low inertia for fast starts, stops, and reversals, while the high resistance provides a nearly linear speed-torque relationship for accurate control.

Servomotors are wound with two phases physically at right angles or in space quadrature. A fixed or reference winding is excited from a fixed voltage source, while the control winding is excited by an adjustable or variable control voltage, usually from a servo-amplifier. The windings are usually designed with the same voltage-turns ratio, so that power inputs at maximum fixed-phase excitation and at maximum control-phase signal are in balance.

In an ideal servomotor, torque at any speed is directly proportional to control-winding voltage. In practice, however, this relationship exists only at zero speed because of the inherent inability of an induction motor to respond to voltage input changes under conditions of light load.

The inherent damping of servomotors decreases as ratings increase, and the motors have a reasonable efficiency at the sacrifice of speed-torque linearity. Most larger motors have integral auxiliary blowers to maintain temperatures within safe operating ranges. Servomotors are available in power ratings from less than 1 to 750 W, in sizes ranging from 0.5 to 7-in. OD. Most designs are available with modular or built-in gearheads.

Ac linear motors

The first linear motor was conceived by Wheatstone more than a hundred years ago. But large air gaps and low efficiencies prevented linear motors from being widely used. Though they still have relatively large air gaps, linear induction motors are increasingly chosen for material-handling applications because they are quieter, more reliable, and less expensive than rotary motors. And because linear motors do not drive

escap®

Motion Systems

Product Overview

escap® from mind to motion

Circle 358

D.C. motors with ironless rotor and precious metal commutation
D.C. tachogenerators and motor-tacho units

D.C. motors with precious metal commutation

escap® D.C. motors with ironless rotor are designed for voltages ranging from 1 V to 60 V. They deliver continuous torques up to 50 mNm and they offer high reliability and long life.

Advantages

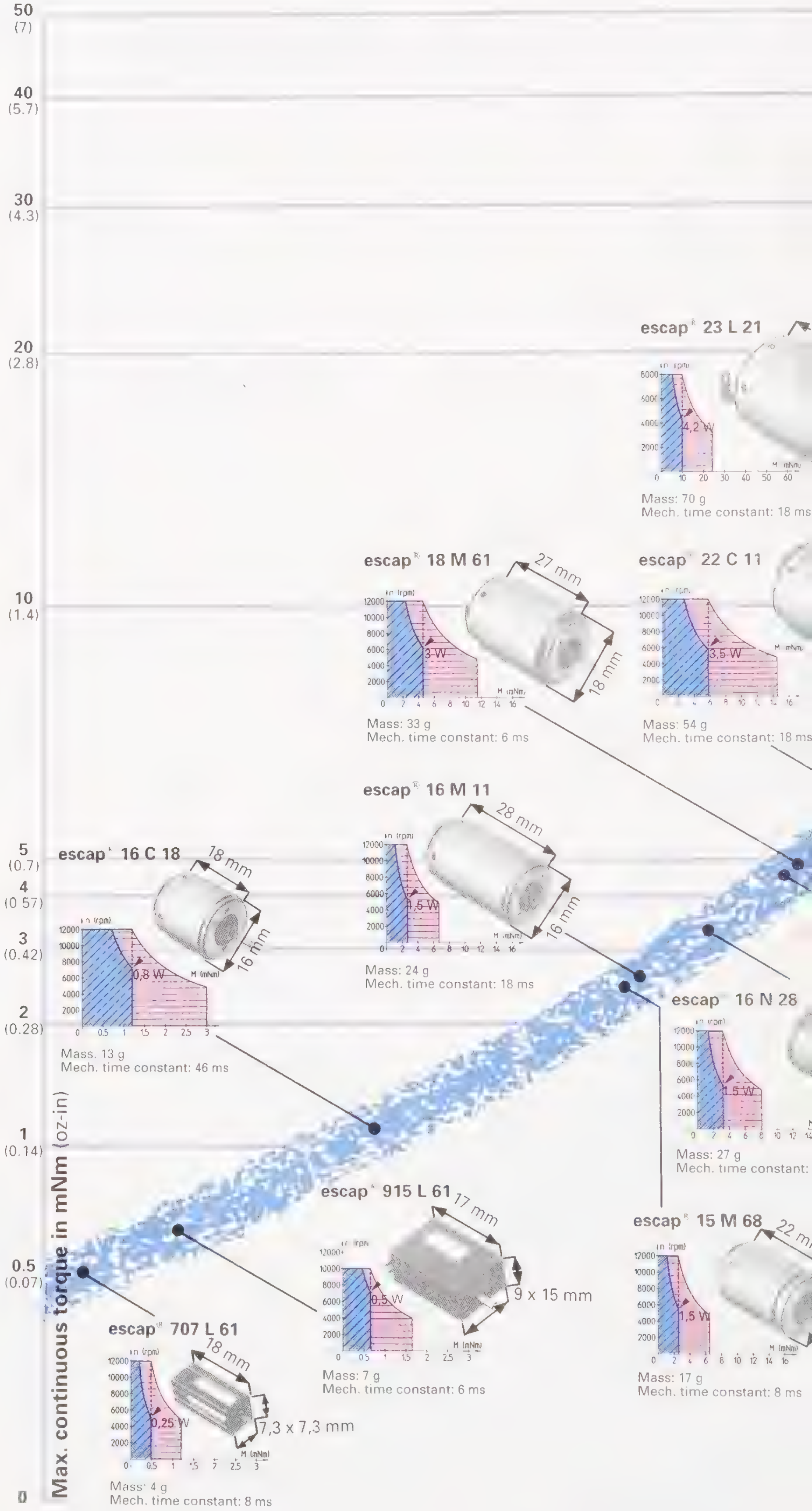
- high power in a small envelope
- very high efficiency
- 10 000 rpm can be reached in just a few milliseconds
- starting voltages below 100 mV
- large choice of characteristics for each motor type.

This overview presents the range of D.C. motors with ironless rotor and precious metal commutation, listed in order of maximum continuous torque, and the values of diameter, length, weight, and mechanical time constant. A speed-torque diagram shows the operating range for:

🟦 continuous operation

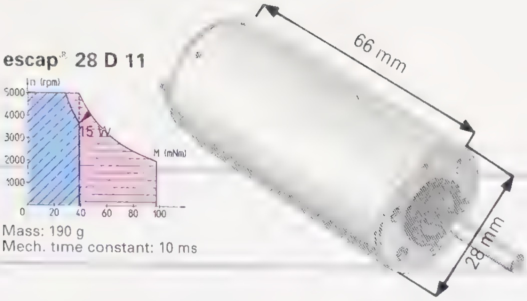
🟪 intermittent operation

Most motors are fitted with sleeve bearings and are available with ball bearings. Many motor types are equipped with REE® giving reduced electrical erosion of the commutation system



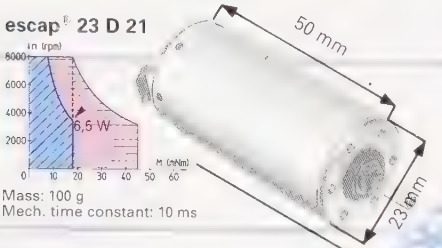
escap®

escap® 28 D 11



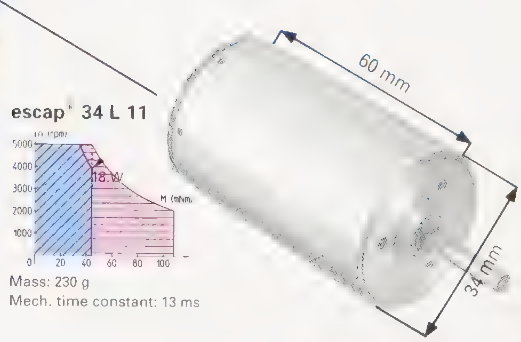
Mass: 190 g
Mech. time constant: 10 ms

escap® 23 D 21



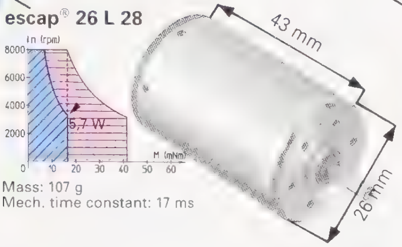
Mass: 100 g
Mech. time constant: 10 ms

escap® 34 L 11



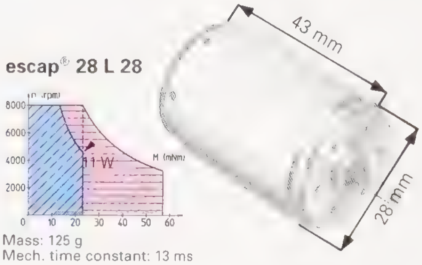
Mass: 230 g
Mech. time constant: 13 ms

escap® 26 L 28



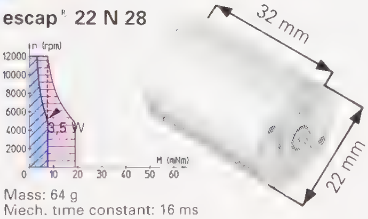
Mass: 107 g
Mech. time constant: 17 ms

escap® 28 L 28



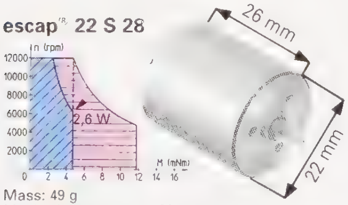
Mass: 125 g
Mech. time constant: 13 ms

escap® 22 N 28



Mass: 64 g
Mech. time constant: 16 ms

escap® 22 S 28



Mass: 49 g
Mech. time constant: 20 ms

Portescap, an international team devoted to the analysis and satisfaction of your particular requirements.

This summary presents the range of standard escap® products. A detailed description of each item is found in the escap® general catalogue available on request.

D.C. tachogenerators and motor-tacho units

The escap® ironless rotor technology with permanent magnet stator provides a linear relationship between angular velocity and tacho signal, a low inertia, and negligible friction.

In addition, all tachos can be fitted with "Tachoplus", an integrated circuit ensuring a clean and undisturbed tacho signal. A bipolar power supply of ± 5 V to ± 18 V is required, and tacho length is increased by just 1 mm.

Tacho type	voltage at 1000 rpm [V]	average ripple peak-peak [%]	resonance frequency [Hz]	dimensions [mm]	mass [g]
22 C 14	5.5	10		22 x 32	54
28 C 24	3.8	6		28 x 31	78
28 L 24	13.5	6		28 x 43	125
Motor-tacho type					
23 HL 11	0.84	7	2000	23 x 55	85
23 HD 11	0.84	7	2000	23 x 68	120
28 HL 18	0.84	7	2000	28 x 62	140
28 GD 11	5.2	7	800	28 x 98	270

The motor-tacho units are assembled using a single shaft, giving excellent mechanical stability.

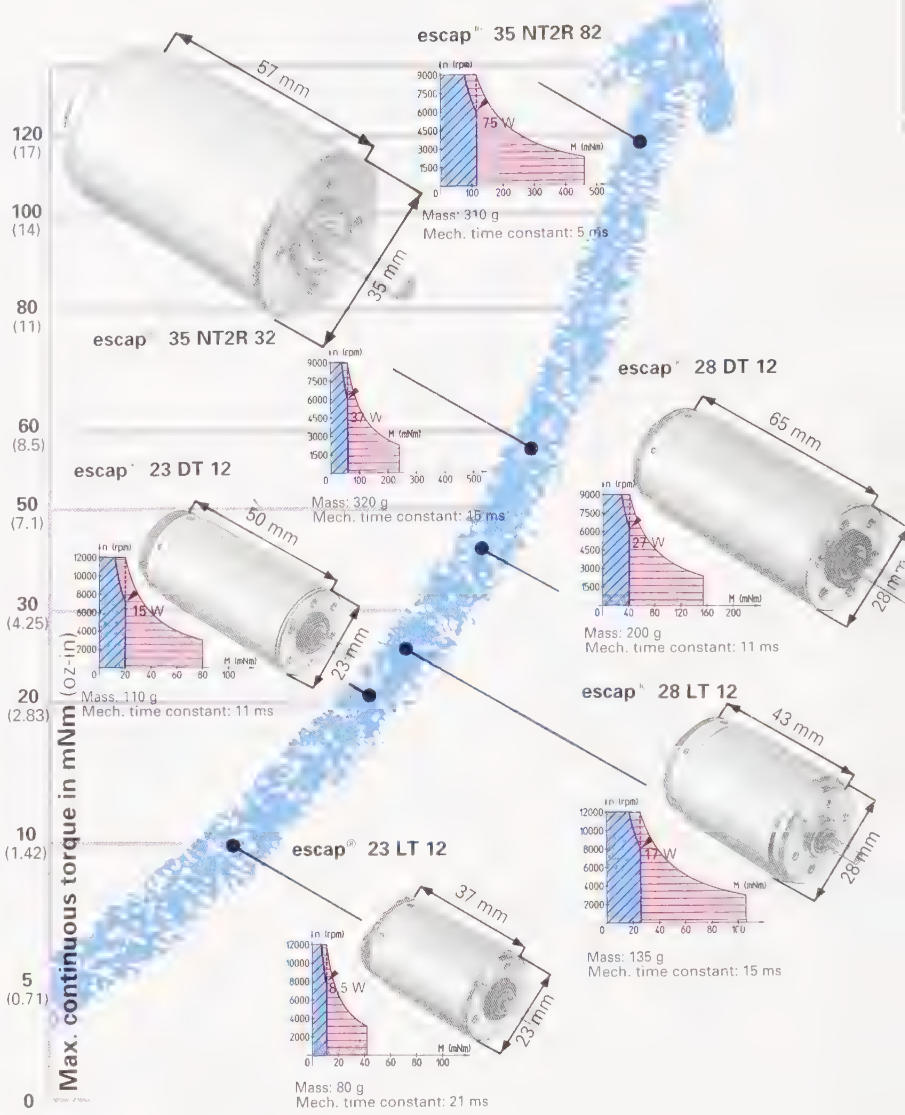
D.C. motors with ironless rotor and Rotafente™ commutation
Integrated encoders

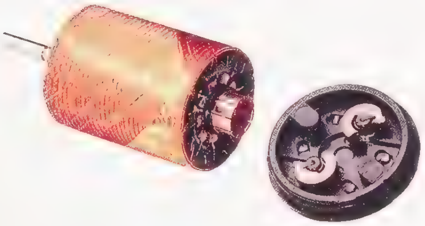
D.C. motors with Rotafente™ commutation

The Rotafente™ copper/graphite commutation system provides the optimum solution for applications requiring high continuous and peak torques, and where high current densities must be commutated such as with modern chopper drivers.

Advantages

- exceptionally high peak and continuous currents with no risk of demagnetisation
- high peak torques for fast incremental motion
- very long life
- excellent resistance to shocks and vibrations
- large choice of characteristics for each motor type.

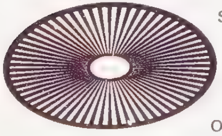




The motor types 23 DT12, 28 DT12, 35 NT2R 32 and 35 NT2R 82 are also available with optical encoder types HP HEDS 5000, 5010, 5500 and 5540.

Integrated optical and magnetic encoders

The integration of encoders into escap® motors results in drive and position systems of high reliability as required with advanced control system techniques. The B and C type optical encoders deliver sinusoidal output signals. By adding the S or P circuit, TTL/CMOS logic signals are obtained.
The D type magnetic encoder provides 2 channels in quadrature, TTL/CMOS compatible, in a diameter of just 16 mm.
For applications requiring a higher resolution, many escap® motors may be assembled with the HP encoders HEDS 5000, 5010, 5500, 5540.



Motor type	Max. number of pulses per revolution				increase in motor length [mm]
	encoder B 1 channel	encoder B 2 channels	encoder C 1 channel	encoder D 2 channels	
16 C 11			16		3
16 M 11			16		3
16 N 28				16	3
M 1616 C/M				16	3
MA 1616 C/M				16	3
MD162R16M				16	3
22 S 28				16	3
22 C 11			16		3
22 N 28				16	3
23 L 21	192	144	32		8 or 3
23 D 21	192	144	32		10 or 3
26 L 28	256	192			9
28 L 28	256	192			9
28 D 11	256	192			5
28 GD 11	256	192			7
34 L 11	360	192			6

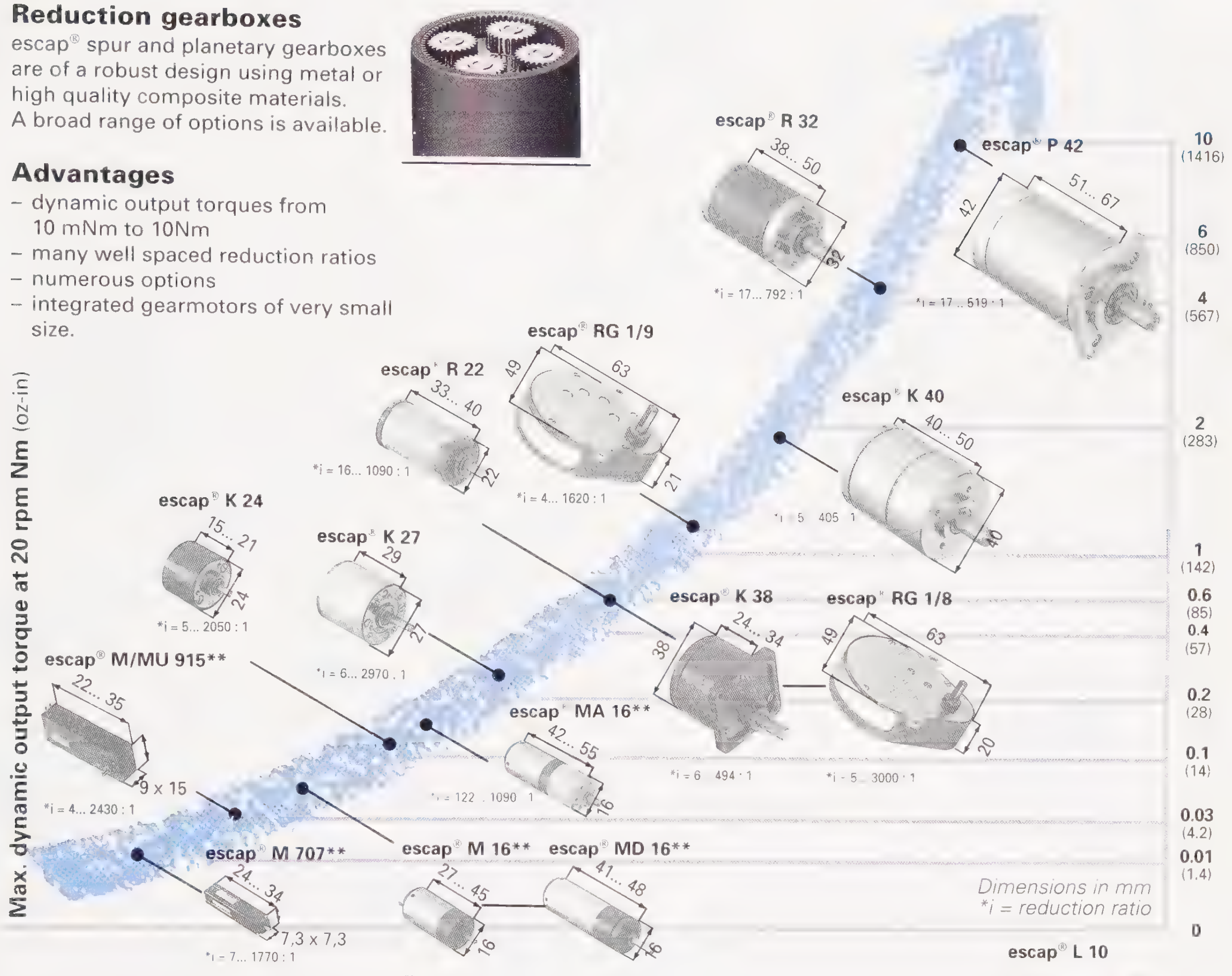
Reduction gearboxes and gearmotors

Reduction gearboxes

escap® spur and planetary gearboxes are of a robust design using metal or high quality composite materials. A broad range of options is available.

Advantages

- dynamic output torques from 10 mNm to 10Nm
- many well spaced reduction ratios
- numerous options
- integrated gearmotors of very small size.



escap® L 10

Standard combinations with escap® motors

	D.C. motors and precious metal commutation													D.C. motors and Rotafente™ Commutation					BL DC motors		Stepper Motors				
	707 L 61	915 L 61	16 C 18	15 M 68	16 M 11	22 S 28	22 C 11	22 N 28	23 L 21	26 L 28	23 D 21	28 L 28	34 L 11	23 LT 12	28 LT 12	28 DT 12	35 NT 32	35 NT 82	26 BC.A	26 BC.C	P 310	P 520	PP 520	P 530	P 532
L 10									●			●									●				
M 707**	●																								
M / MU 915**		●																							
M 16**			●		●																				
MD 16**			●		●																				
K 24							●	●	●	●									●	●	●				
MA 16**			●		●																				
K 27							●	●	●	●									●	●	●				
K 38										●		●		●	●	●			●	●					
RG 1/8							●	●	●	●	●	●							●	●	●				
R 22						●	●	●	●	●		●		●	●						●				
K 40										●		●			●		●	●				●	●	●	●
RG 1/9									●	●	●	●		●	●							●	●	●	●
R 32												●		●	●	●	●	●							
P 42													●			●	●	●							

The escap® L10 is a linear actuator using an M6 spindle having a pitch of 1 mm per revolution. It includes reduction ratios from 5:1 to 100:1 and has a rated linear thrust of 100N at 2mm/s.

***The type M... gearboxes form part of an integrated gearmotor. The type MU features a right angle output stage.*

Most gearboxes are available with either sleeve bearings or ballbearings and have a recommended temperature range from -30° to +65°C

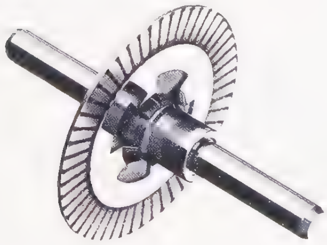
Disc Magnet Stepper Motors
Drive Circuits

Stepper Motors

The disc magnet technology of escap® two-phase stepper motors includes a rotor consisting of a thin disc of rare earth material, and of a very short magnetic circuit using high quality Si-Fe laminations. Therefore, iron losses are kept to a minimum, and dynamic performance is far superior to conventional stepper motors.

Advantages

- very low inertia
- very low losses
- boost capability
- exceptionally high acceleration
- high starting frequency and peak speed
- particular models for microstep operation
- high power/weight and power/volume ratios.



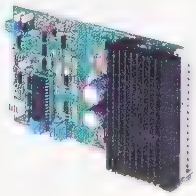
The motors P 310, P 430, P 520, P 530, PH 632, P 630 et P 850 are specially designed for microstepping mode

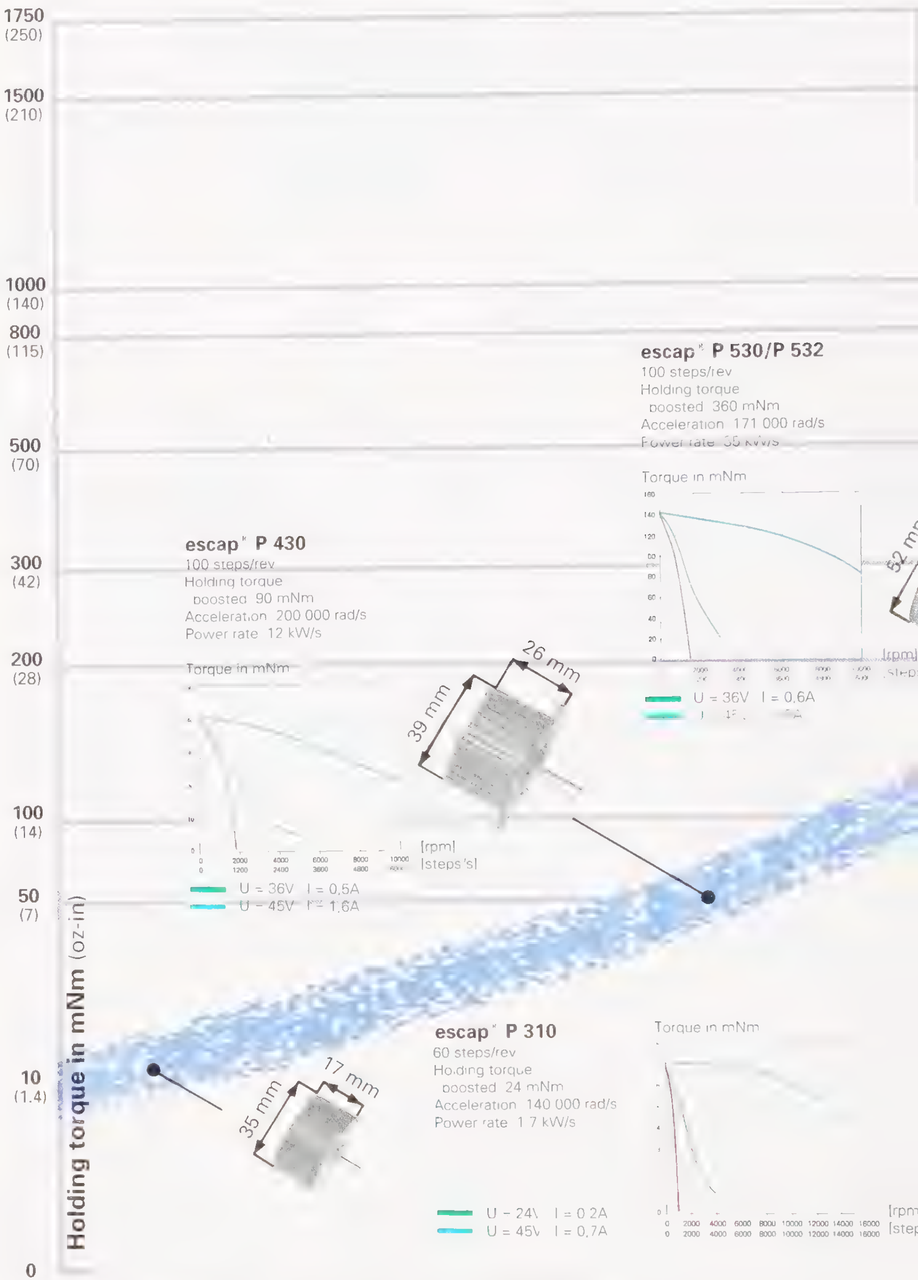
Various combinations of stepper motors and gearboxes are available in addition to the standard combinations proposed on page 5

The motor type PP 520 has integrated Hall sensors and may be operated as a brushless D.C. motor with automatic commutation

Drive circuits

The drive electronics offered by Portescap are fully adapted to the disc magnet technology for all kinds of applications. They fully utilize the motor performance in full step, half step and microstep mode.



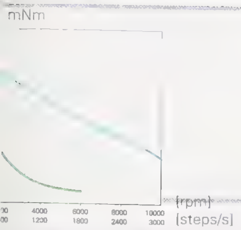


Recommended motor/driver combinations

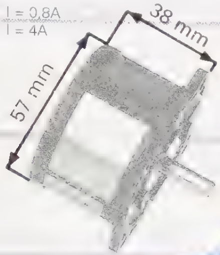
	P 310	P 430	P 520	PP 520	P 530	P 532	PH 632	P 630	P 632	P 850	P 852	P 952
ELD 200	●	●	●	●		●	●					
EDI 201	●	●	●	●	●		●	●		●		
EDB 462	●	●	●	●		●	●		●		●	
EDB 463			●	●		●	●		●		●	
EDM 453	●	●	●	●	●		●	●		●		
EDI 401	●	●	●	●	●		●	●		●		
ESI 402*	●	●	●	●		●	●		●		●	
EDB 106						●	●		●		●	●
EDM 107					●			●		●		●
EDB 1010									●		●	●

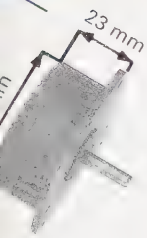
Driver and controller for demonstration

' PH 632
:/rev
orque
: 450 mNm
ion: 115 000 rad/s²
:e: 40 kW/s

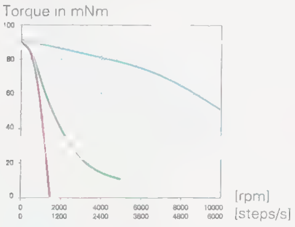


= 36V I = 0,8A
= 45V I = 4A



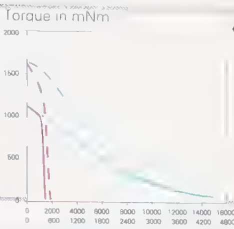


escap® P 520/PP 520
100 steps/rev
Holding torque
- boosted. 250 mNm
Acceleration. 120 000 rad/s²
Power rate: 17 kW/s



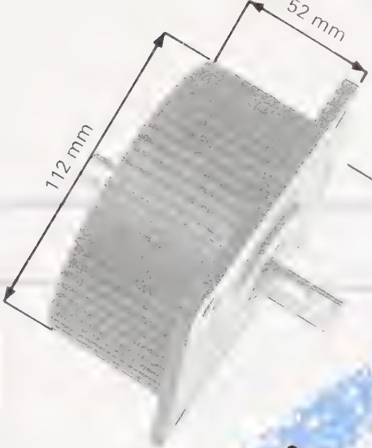
- 🟩 U = 36V I = 0,8A
- 🟦 U = 45V I = 4A

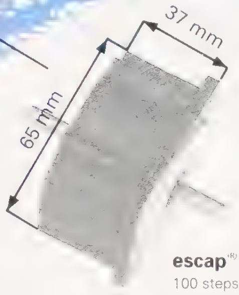
escap® P 952
200 steps/rev
Holding torque
- boosted 2500 mNm
Acceleration 76 000 rad/s²
Power rate 122 kW/s



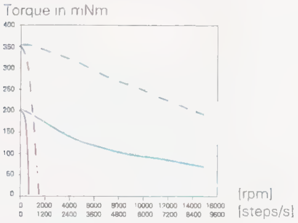
[rpm]
[steps/s]

U = 80V I = 6A
U – 80V I = 9A



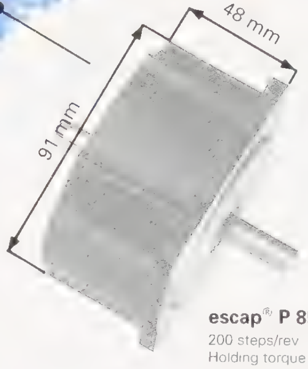


escap® P630/P 632
100 steps/rev
Holding torque
- boosted 600 mNm
Acceleration: 90 000 rad/s²
Power rate: 31 kW/s

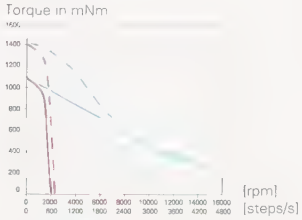


U = 80V I = 3,6A
U = 80V I = 7A

- Pull in
- Pull out, voltage drive, (L/R)
- Pull out, current source, (PWM)
- Pull in, boosted
- Pull out, boosted



escap® P 850/P 852
200 steps/rev
Holding torque
boosted 1880 mNm
Acceleration 81 000 rad/s²
Power rate 86 kW/s



U = 80V I = 6,5A
U = 80V I = 9A

Portescap, an international team devoted to the analysis and satisfaction of your particular requirements.

This summary presents the range of standard escap® products. A detailed description of each item is found in the escap® general catalogue available on request.

Stepper Motor Drive Circuits

	ELD 200	EDI201	EDB462	EDB463	EDM 453	EDI 401	ESI 402*	EDB 106	EDM 107	EDB 1010
Chopper driver		●	●	●	●	●	●	●	●	●
Constant voltage driver	●									
Max. current per phase [A]	0.8	2	2	3	3	4	4	6	7	9
Max driver voltage [V]	36	34	40	40	45	34	45	80	80	80
On-Board clock	●	●				●	●			
Full/half step mode	●	●	●	●	●	●	●	●	●	●
Microstep mode		●			●	●			●	
Boost/standby current		●	●	●	●	●		●	●	●
Electronic damping		●				●				
Dimensions [mm]	160x112x15	160x100x35	61x74x32	76x74x32	160x100x30	160x100x35	160x100x35	126x74x32	150x76x30	126x74x32

Driver and controller for demonstration

Circle 358

Brushless motors with electronic commutation

escap®

In this new escap® motor series the ironless rotor technology is combined with the electronic commutation used with brushless D.C. motors. This results in total reliability and outstanding motor life even at very high speeds.

The type 26BC.A motor with integrated electronic commutation

All the components required to run this motor are integrated internally. This simplifies the motor implementation in the application.
The standard version includes six leads and allows for a separate motor and logic supply necessary at very low speeds. In addition, start-stop and direction of rotation may be controlled through logic inputs, and a tacho signal is available for speed control.

escap® applications...

- data processing
- telecommunications
- instrumentation
- avionics, aerospace
- automotive
- optics, audio, video
- industrial automation
- security systems
- environmental control systems
- medical equipment
- military equipment
- robotics
- office equipment

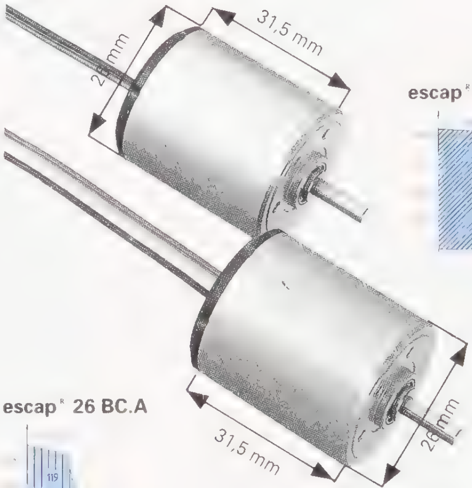
...serving every type of industry

Portescap
An international presence

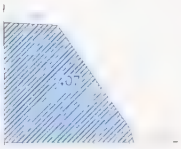
Founded in La Chaux-de-Fonds, Switzerland in 1931, Portescap has since become a world leader in motion control.
Portescap is the partner which, through its worldwide presence and a team of specialists, can provide a complete solution to all problems of designing, developing and manufacturing motion control systems.

escap® is the registered trade mark of Portescap.

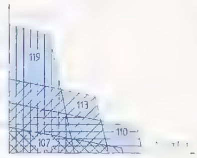
The type 26BC.C motor with external commutation and without sensors



escap® 26 BC.C



escap® 26 BC.A



With the revolutionary Tetradrive™ concept the motor phase windings are used in a bridge type configuration. This way the rotor position is determined by observing back-EMF rather than by sensors inside the motor. The logic signals for electronic commutation are generated in the escap® 3LS integrated circuit.
The escap® ETD3002 drive electronics combines all the functions necessary for the automatic commutation and also includes a 2 A/30 V driver.
The Tetradrive™ concept allows for full utilization of the motor performance even in a hostile environment such as severe conditions of temperature, shock and vibration, as the motor only contains copper, iron laminations, and the magnet.

This summary presents the range of standard escap® products. A detailed description of each item is found in the escap® general catalogue available on request. Please contact the address nearest to you to receive your copy.

Portescap
157, rue Jardinière
CH-2301 La Chaux-de-Fonds 1
Tel. (039) 25 61 11
FAX (039) 25 65 90

Portescap Deutschland GmbH
Gülichstrasse 12
D-7530 Pforzheim
Tel. (0 72 31) 4900-0
FAX (0 72 31) 4900-20

Portescap France SA
Le Trident
3-5, Voie Félix-Eboué
F-94024 Créteil Cedex
Tel. (1) 48 98 99 66
FAX (1) 48 98 99 55

Portescap Japan Ltd
7-10 Nihombashi-honcho
4-chome
Chuo-ku, Tokyo 103
Tel. (03) 3241-0201
FAX (03) 3241-0221

Portescap
Przedst. w Polsce
00-950 Warszawa
ul. Stawki 2, 37 piętro
Tel. (2) 6351399
FAX (2) 6355743

Portescap Sverige AB
Grev Turegatan 20
S-11446 Stockholm
Tel. (08) 6610505
FAX (08) 6614012

Portescap (UK) Limited
55 Cobham Road
Ferndown Industrial Estate
Wimborne, Dorset BH21 7RA
Tel. (0202) 861500
FAX (0202) 861700

Portescap U.S. Inc.
36, Central Avenue
Hauppauge, N.Y. 11788
Tel. (516) 234-3900
FAX (516) 234-3986

Australia
Magnetic automation Pty Ltd.
Tullamarine
Tel. (03) 3301033
FAX (03) 3381398

Belgique
Telerex SA
Antwerpen-Deurne
Tel. (03) 326 40 00
FAX (03) 326 31 17

Danmark
Gearcentralen A/S
Sønderborg
Tel. (74) 42 18 64
FAX (74) 42 18 94

España
Anatronic SA
Madrid
Tel. (1) 542 44 55
FAX (1) 248 69 75

India
O.E.N.
Micro Systems Ltd.
Cochin
Tel. (484) 35 31 32
FAX (484) 360 287

Israel
Electrondart Ltd.
Petah Tikva
Tel. (03) 9314447
FAX (03) 9302867

Italia
Deltaomega Srl.
Milano
Tel. (2) 57606510
FAX (2) 57606551

Nederland
Telerex Nederland BV
Breda
Tel. (076) 715000
FAX (076) 711477

Norge
Elra A/S
Oslo
Tel. (02) 750330
FAX (02) 750340

Österreich
Burisch GmbH & Co. KG
Wien
Tel. (0222) 3876380
FAX (0222) 301643

Singapore
Bertda Services
(SEA) PTE Ltd.
Singapore
Tel. 7460112
FAX 4694752

South Africa
Strand Trading Pty Ltd.
Johannesburg
Tel. (11) 8376168/9
FAX (11) 8378557

South Korea
J & C International Inc
Seoul
Tel. (2) 808-8161/3
FAX (2) 808-8160

Suomi Finland
C. Casagrande & CO Oy
Helsinki
Tel. (90) 640711
FAX (90) 644488

Taiwan
Unist Business Corp.
Taipei
Tel. (02) 3634488
FAX (02) 3630685

Circle 358

Printed in Switzerland 11 91/6523

gearboxes or rotary-to-linear conversion devices, they can be more efficient.

A linear motor is conceptually a rotary motor whose stator core has been cut and unrolled. The circular stator becomes a linear stator, defining a single-sided linear induction motor (SLIM). Likewise, if the circular stator is cut into two sections and flattened, the motor becomes a double-sided linear induction motor (DLIM).

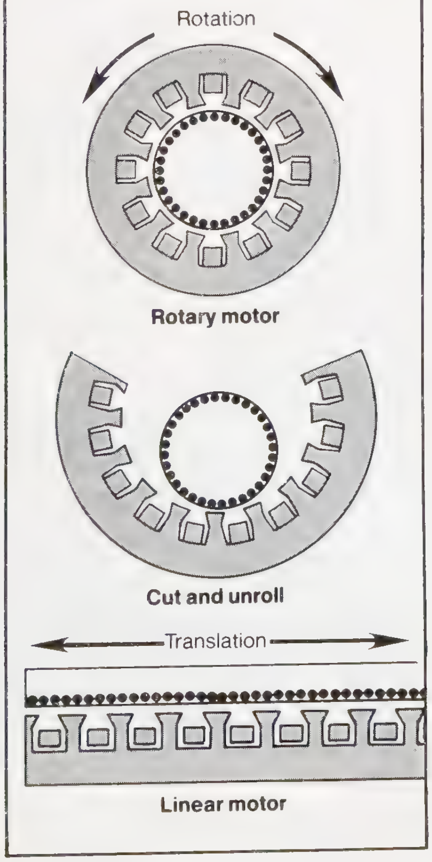
The DLIM and SLIM both require a two or three-phase stator (primary) winding and a flat metallic or conductive plate-type armature (secondary).

Cutting and unrolling the stator leads to many other possible linear motor configurations. For example, a tubular motor can be conceptually made from the SLIM by rerolling it in the direction of motion. The pole pattern is produced by three-phase windings in alternate clockwise and counterclockwise directions around the tube. Other designs are also possible, but few of them are used.

There are several important differences between linear and rotary induction motors that bear on selection. Unlike rotary motors, the linear motor has a beginning and an end to its travel.

First, the moving secondary material enters the primary at one end of the motor and exits at the opposite end. Induced currents in the secondary material at the entry edge resist air-gap flux buildup. And at the exit edge, the material retards the air-gap flux decay. This results in an uneven air-gap flux distribution. Such flux distribution causes little or no thrust under the first few poles at entry and a braking thrust at exit.

LINEAR MOTOR DEVELOPMENT



At stall and low speeds, the flux distribution is not seriously distorted and is usually ignored. But dynamic compensation is required to minimize thrust roll-off at high speeds.

Second, the large air gap which is endemic to linear motors effectively limits linear force. Fortunately, new pole piece designs offset the adverse air-gap effect.

The moving member in a linear motor is typically a solid conducting plate or sheet. It does not contain coils or windings. However, a linear motor can be constructed so the primary moves and the secondary remains stationary.

Linear motors also need the secondary to be wider than the primary. The secondary should be wide enough to handle induced current with little resistive losses along the transverse edge. Such losses are known as transverse edge-effects which can reduce useful thrust or force.

A normal force between stator and armature in the SLIM is perpendicular to the direction of travel. The stator and armature are either attracted or repelled by this force. Factors that determine the force direction include armature material composition and thickness, stator frequency, air gap, and pole pitch. SLIMs are constructed to minimize the normal force. For DLIMs, and rotary and tubular motors, these forces cancel.

Linear induction motors produce up to several thousand pounds of thrust. Positional accuracies of 1 μin. and velocities of 100 in./s are possible. Feedback is usually from a linear encoder able to provide high resolution and accuracy. Among the encoder technologies used are optical, magnetostrictive, magnetic, and inductive.

For applications involving high accelerations, the secondary normally moves over a long stationary primary. High force and short stroke applications with low repetition rates call for a moving primary and a long stationary secondary. Conversely, for long strokes and high repetition rates, a moving secondary and long stationary primary are required.

In certain material-handling and coil-processing applications using linear-induction motors, the material itself is the secondary. For example, to handle sheet steel, overhead SLIM primaries induce currents in the steel and attract it to the primary. A balanced force is provided by gravity and an air bearing to levitate the sheets in air. The sheets are then propelled into piling zones without touching any surface or other object.

Recent advances in power electronics, microprocessors, and electromagnetic analysis software are responsible for many new linear-motor designs. Power electronics provide inexpensive pulse-width modulators (PWMs), vector controllers, and variable-frequency drives. Microprocessors used for control include 32-bit processors, coprocessors, and digital signal processors (DSPs). Precision control is needed to compensate for magnetic saturation, thrust roll-off, and transverse-edge effects.

Definite and special-purpose motors

Definite-purpose motors handle specific applications and have well-established NEMA standards. They are produced in high volume, and are low in cost when compared to general-purpose motors with the same ratings.

To apply a definite-purpose motor for a duty other than that for which it was intended must be carefully considered. Modifications can be made easily and inexpensively. Other modifications may require special tooling, increasing cost. The electrical characteristics of the motor must be checked very closely against the load. Testing the motor with the application is recommended.

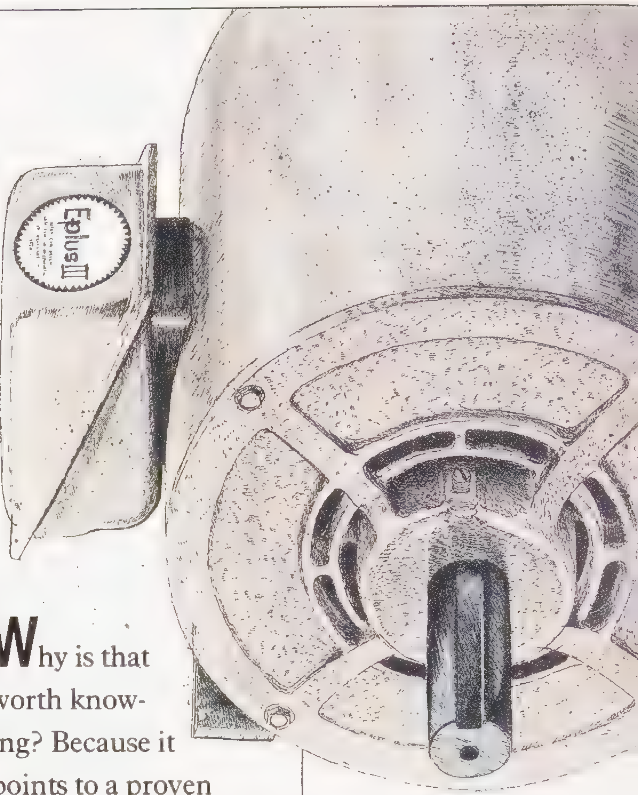
Instrument motors: Instrument motor definitions vary with users and manufacturers of motors. Generally, an instrument motor is a precision motor with fractional or subfractional horsepower ratings. Sizes range from ¼ to ¾-hp units.

Gearmotors: A gearmotor consists of a gear-reduction unit with an integral or flange-mounted rotor. The main advantage of a gearmotor is that the driving shaft may be coupled directly to the driven shaft. Belts, pulleys, chains, or additional gearing to step down motor speed are not needed. Also, coupling or belting of a motor to a separate speed-reducer unit is eliminated.

***Torque requirements**:* Starting and running torques are considered separately because starting characteristics of the motor and gearing differ. Applications needing high breakaway torques require careful selection of the

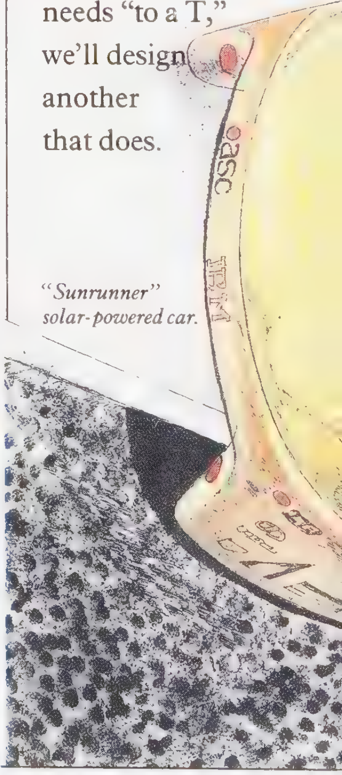
"I didn't know MagneTek did that!"

You probably know that MagneTek makes electrical equipment. But did you know that MagneTek designers developed the first *Energy Engineered™* electric motors, drives, transformers and power supplies decades ago?



Why is that worth knowing? Because it points to a proven source of information on electrical and electronic components and subsystems designed with energy optimization in mind.

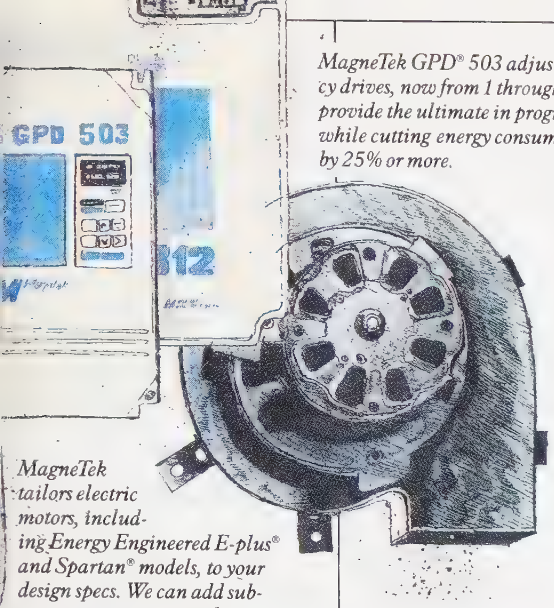
Take electric motors. MagneTek offers the widest range of high-efficiency motors in the business, including fractional-horsepower PSC types. If one doesn't suit your needs "to a T," we'll design another that does.



"Sunrunner" solar-powered car.

ENERGY ENGINEERED

© 1991 MagneTek, Inc.



MagneTek GPD® 503 adjustable frequency drives, now from 1 through 500 Hp, provide the ultimate in programmability while cutting energy consumption by 25% or more.

MagneTek tailors electric motors, including Energy Engineered E-plus® and Spartan® models, to your design specs. We can add subsystem components, such as integral blower housings – and we get samples to you when you need them.

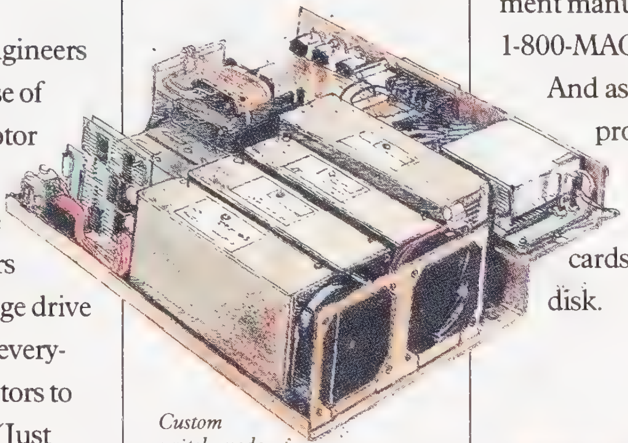
Example: An experimental MagneTek brushless DC motor powered the University of Michigan's top U.S. entry in the 1991 World Solar Car Challenge.

Drives? Our engineers pioneered the use of transistors in motor control circuits, and today we are helping designers build leading-edge drive technology into everything from elevators to HVAC systems. (Just call 1-800-762-4860 and ask for Ed Peterson or one of our other drive engineers.)

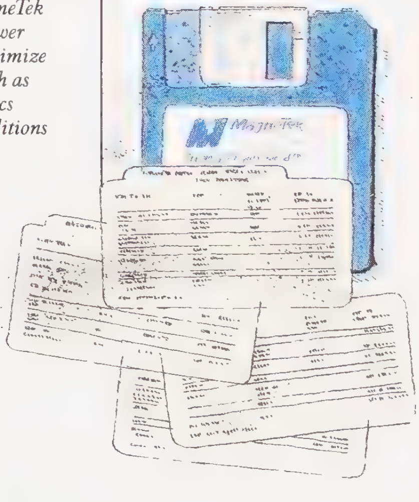
Transformers? MagneTek has the largest selection of component transformers and specialized lighting ballasts to be found anywhere. Also transducers, accelerometers, position controls and capacitors. And MagneTek custom power supplies, both linear and switch-mode, 5W-2,000W, are the most advanced available, featuring power factor correction and integral circuit protection.

To get the facts about these and many more *Energy Engineered* products from one of America's largest electrical equipment manufacturers, call 1-800-MAGNETEK.

And ask for your free product directory on either Rolodex cards or floppy disk.



Custom switch-mode power supplies from MagneTek incorporate advanced power quality technology to minimize unwanted side effects such as EMI radiation, harmonics and non-linear load conditions on the circuit.



MagneTek

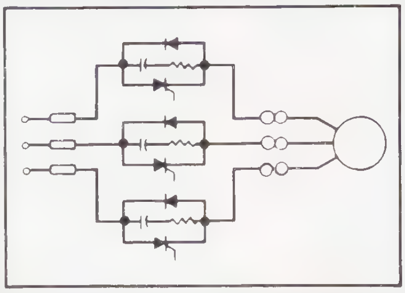
11150 Santa Monica Blvd., Los Angeles, CA 90025

Call 1-800-624-6383 (MAGNETEK). Your source for *Energy Engineered* lighting ballasts, transformers, motors, drives, generators, condensers and power supplies.

SOLID-STATE MOTOR STARTERS

Solid-state starters use semiconductor power and trigger circuits instead of mechanical contacts. The motor is accelerated from standstill to maximum speed by varying motor voltage from zero to full voltage on a stepless ramp. Acceleration time is adjustable up to about 10 s by means of a trimmer potentiometer in the trigger circuit. The starter is activated by closing a remotely located switch wired to the starter terminals. Units have provisions for either 2 or 3-wire control.

These starters produce negligible inrush current and minimum mechanical shock to the driven load as the motor starts. The result is often increased life of motors, gears, and other mechanical components. Some starters provide ramped-down motor voltage when the control contacts are opened. This does not decelerate the load, but brings the motor to a gradual stop.



Power semiconductors in each power line can be two SCRs or an SCR and a diode. The latter configuration, shown here, requires a simpler control circuit. Some starters are hybrid units using both SCRs and contactors. The contactors connect the SCRs in the motor circuit only during start-up.

Ramped-down stopping eliminates mechanical shock to low-inertia loads that might otherwise suffer harmful effects from abrupt stopping. High-inertia loads are unaffected by this feature.

In addition to thermal overload protection, solid-state starters provide protection against phase loss and phase reversal. Units are available for operation on three-phase line voltages from 208 to 600 Vac at 25, 50, or 60 Hz. Horsepower ratings range from 1 to 400 hp.

---

motor because split-phase, polyphase, capacitor-start, and brush-type motors have large starting torques.

Applications with high inertias should be analyzed by the gearmotor manufacturer. This problem is critical with self-locking right-angle gearmotors. Since rotor and load are rigidly connected by the gear train, both must stop in the same time. In severe cases, momentary power failure may be all that is necessary for a high inertial load to destroy the gear train.

Overhung loads are applied to the output shaft of the gearmotor whenever the gearmotor is connected to the applications requiring cams, belts, or gearing. Applications requiring cams, hoisting drums, or switches at the output shaft can also cause very high overhung loads on gearhead bearings.

It is inherent with gearmotors that overhung load capacity decreases as the delivered torque increases. This reduction is caused by internal gear-reduction forces. In small fhp gearheads, reducer bearings may be fully loaded by the reactions resulting from rated torque. Under these conditions, no additional overhung load may be placed on the output shaft.

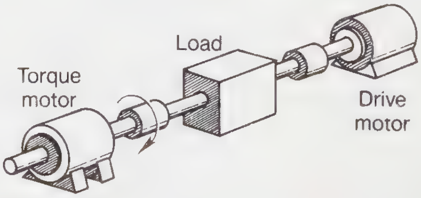
When the overhung-load capacity of a gearmotor is too small, it may be possible to obtain oversize shafts and bearings. A third or outboard bearing is sometimes used to support the end of the driveshaft. However, it is extremely important that this bearing is properly aligned to prevent excessive shaft and bearing loads. Thrust loads are most severe with vertical-shaft units and gearmotors driving a lead screw or axial actuating device. It is often less expensive to specify a heavy-duty unit rather than extensively modify a normal-duty unit when loads are excessive.

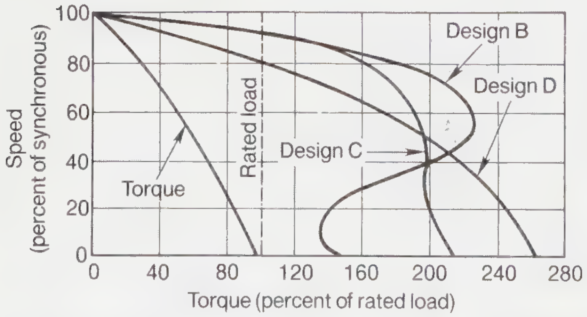
Toothless motors: The power of modern magnets allows motors to contain toothless armatures. Coils are wound and assembled outside the motor, then inserted and secured as a unit

---

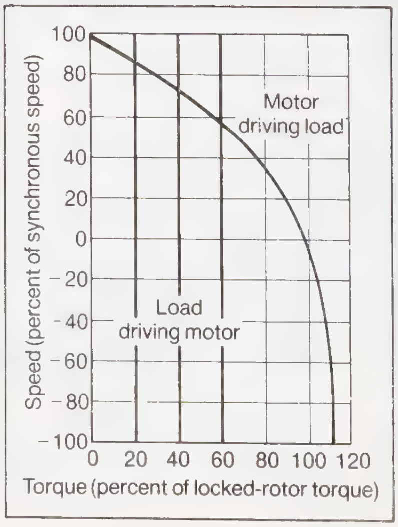
TENSION CONTROL SUPPLIED BY TORQUE MOTORS

Torque motors are sometimes used to apply torque to the shaft in one direction while the connected load is actually driving the shaft in the opposite direction. This condition occurs when the motor is used as a tension-control device. In such applications, the torque motor can supply approximately rated locked-rotor torque while the motor shaft is going in the reverse direction.

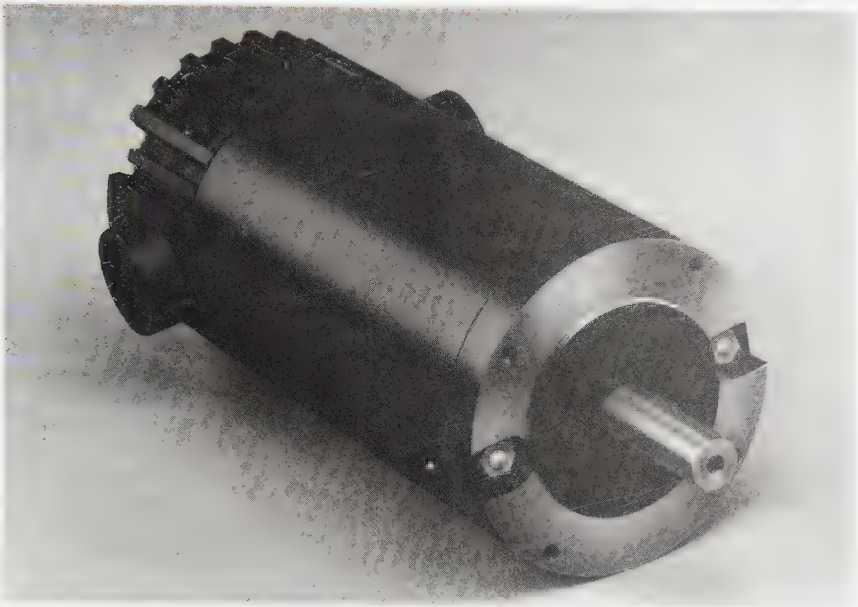




Torque motor develops maximum torque at or near locked rotor. This contrasts with other motors which develop maximum torque at about 60% synchronous speed or lower.



Bison delivers the best value in industrial grade PMDC and Universal Motors and Parts sets!



SERIES 32 MOTOR SPECIFICATIONS CHART

HP RATING (SEE NOTE)	MODEL NUMBER	LINE VOLTAGE V_L (Volts)	FULL LOAD CURRENT I_L (Amperes)	TORQUE CONSTANT K_T (Oz-In/Amp)	TERMINAL RESISTANCE R_T (OHMs)	ARMATURE INDUCTANCE L_m (Millihenries)	ARMATURE INERTIA J_m (Oz-In Sec^2)	PACKAGE LENGTH L_{max} (INCHES)	MOTOR WEIGHT WT. (POUNDS)
1/16 @ 1800 RPM	32.11	12	6.03	7.36	0.337	0.994	0.0201	5.236	5.5
1/12 @ 1800 RPM	32.15	12	7.54	7.55	0.248	0.812	0.0245	5.611	5.9
1/8 @ 1800 RPM	32.24	12	10.81	7.58	0.171	0.537	0.0349	6.486	7.0
1/6 @ 1800 RPM	32.35	12	14.20	7.58	0.122	0.368	0.0486	7.636	8.4
1/4 @ 1800 RPM	32.40	12	24.40	7.65	0.089	0.408	0.0545	8.136	9.1
1/24 @ 1800 RPM	32.11	90	0.56	58.9	21.91	63.6	0.0201	5.236	5.5
1/16 @ 1800 RPM	32.15	90	0.77	58.9	15.76	49.4	0.0245	5.611	5.9
1/12 @ 1800 RPM	32.22	90	0.95	61.6	9 15	37.7	0.0331	6.336	6.8
1/8 @ 1800 RPM	32.29	90	1.35	61.5	6.71	29.2	0.0411	7.011	7.7
*1/4 @ 1800 RPM	32.45	90	3.25	57.8	4.42	20.7	0.0604	9.846	10.3

* 1/4 HP 90 VOLT MOTOR IS TOTALLY ENCLOSED, FAN COOLED (PEFC)

NOTE
12 VOLT MOTORS RATED FOR 1 0 FORM FACTOR POWER SUPPLY
90 VOLT MOTORS RATED FOR 1.4 FORM FACTOR POWER SUPPLY

ALL RATINGS UTILIZE NO HEAT SINK AND WERE DEVELOPED FOR OPERATION IN A 25°C AMBIENT

World-class quality!

- Microprocessor-controlled winding and welding.
- Dynamically balanced armatures.
- Diamond turned commutators.
- Integral brush protection.
- Up to 30% longer wearing brushes.
- High quality zinc alloy castings.
- Finned end bells.
- Tang-type commutators.
- Standard horsepower ratings.
- A full range of mounting options.
- Highest grade ceramic magnets.
- Class H polyester trickle varnishing.
- Double shielded ball bearings.
- Carbon steel shafts.
- UL recognized.

Bison Motors are ideal for these applications:

Door openers, battery operated vehicles, servo systems, welding wire feeders, computer components, robots, medical equipment, conveyers, packaging equipment, and others.

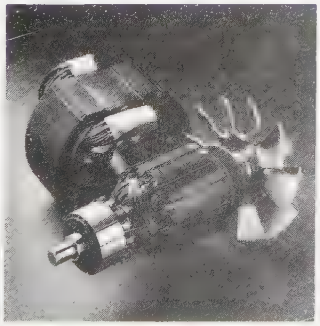
Complete choice of options for OEMs.

Bison Electric offers quantity buyers standard, modified, and completely custom motors designed to meet specific application parameters. Options include round or square end bells, mounting bases, lead lengths, voltages, special shaft designs and materials, metric mounting, and tachometer or brake mounting. And we promise the fastest turn-arounds in the industry!

Bison, a trusted name in gearmotors, is now a name you can count on for motors too. Please call for additional information or quotations.

Motor parts sets

The Bison Electric plant has been manufacturing Universal parts sets for more than 30 years. Value sensitive OEMs use them, in quantity, in such air moving applications as vacuum systems for floor care and insulation blowers; in portable and stationary power tools; in commercial restaurant equipment, and in appliances. They are made on state-of-the-art equipment to very high quality specifications. Our capabilities include design, prototyping, and in-house testing. For samples and additional information, please contact a Bison application engineer.



Ratings: from 1⁄10 to 3 HP

Speeds: 1,000 to 20,000 RPM

Voltage: 12 to 230 volts, AC or DC.

Frame Sizes: B (2,4375 dia.), K (3.187 dia.) and PQ (3.687 dia.)

Stack Lengths: Frames B and K up to 3″ and PQ up to 4″

Armature construction: Double or single insulated with diamond turned commutators, fused lead connections, and two plane dynamic balancing for extended brush life and reduced vibration.

Varnish: Armatures are impregnated with Class H polyester varnish to provide high temperature protection.

Quality: All parts sets are checked dielectrically twice to assure performance of our UL approved product. Both insulation system and construction are recognized as Class B.

BISON
Electric Corporation

2620 W. Fletcher Ave. ▪ Chicago, IL 60618 ▪ Phone: 800-AT-BISON ▪ FAX: 708-968-3049

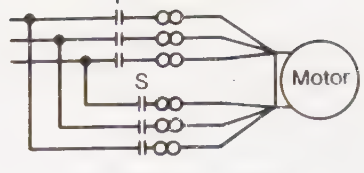
Circle 359

in the armature.

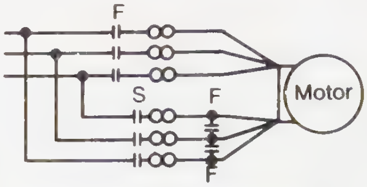
Toothless construction provides more space for armature coils and provides higher current ratings. Iron losses are cut by 50%, and armature inductance approaches that for cup motors. Toothless motors do not cog at low speed. And because coil insertion is easier, motor diameters can be smaller.

In toothless motors that use ceramic magnets, flux density in the air gap is much lower than in conventional motors. The low density results from the large air gap, an inherent characteristic of toothless construction.

Toothless motors equipped with rare-earth magnets, however, operate at high flux densities. These motors contain magnets that are about the same length as the air gap. With this relationship, rare-earth magnets operate at flux levels that are close to the magnet's maximum energy product.



TWO-WINDING MOTOR



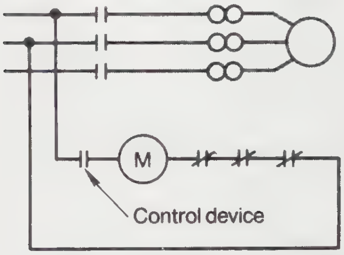
SINGLE-WINDING MOTOR

Power connections for starting two-winding and single-winding two-speed, squirrel-cage motors.

STARTING UP

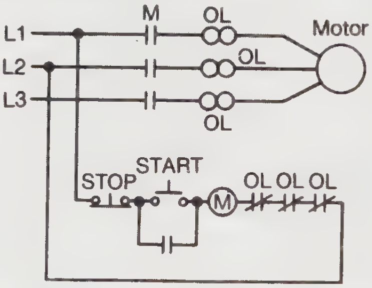
Magnetic starters: A magnetic starter contains a mechanism for opening and closing a set of contacts in the motor circuit and a thermal overload-protective device. When the coil is energized movable contacts complete the electrical circuit. De-energizing the coil opens the circuit. Magnetic starters are frequently controlled by pushbuttons, limit switches, relays, timers, pressure switches, and float switches.

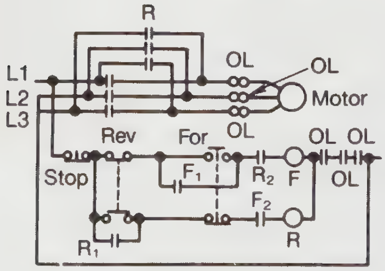
Combination starters: A magnetic starter is combined with a disconnecting means in one enclosure. The disconnect can be a motor-circuit switch, with or without fuses, or a circuit breaker.



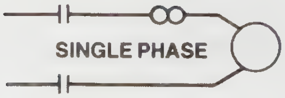
Two-wire control: If a low-voltage condition occurs in the power supply, the magnetic strength of the coil is weakened to permit the contacts to open and stop the motor. When voltage returns to the proper value, the coil again closes the main contacts in the power circuit, since the control-device contacts remain closed.

Three-wire control: Protection against low voltage requires manual intervention to restart the motor when voltage is restored. When the start button is pressed, the control circuit is energized and causes the starter main and auxiliary contacts to close. The auxiliary contact continues to maintain the circuit because it is in parallel with the start button. This is commonly called a holding circuit.

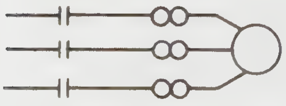




Reversing starters: A characteristic of a three-phase squirrel-cage motor is that the direction of rotation can be changed by reversing any two power leads. This is done by adding another contactor and appropriate mechanical and electrical interlocking equipment to a basic starter. Reversing starters are usually magnetic.



SINGLE PHASE



THREE-PHASE

Manual starters: For small-motor applications, the first consideration is a manual starter. A manual starter makes and breaks the motor circuit. A thermal protective circuit in the starter guards against excessive temperature conditions. Manual starters are limited to single-phase motors up to 5 hp at 230 V and three-phase motors up to 15 hp at 600 V.

Motor starters

Full-voltage, single-speed motor starters: Single-speed squirrel-cage motors have starters that fall into two categories: full-voltage or across-the-line starters; and reduced-voltage starters.

Full-voltage starters (manual and magnetic) apply full voltage directly to motor terminals. Two other types, combination and reversing starters, consist of a starter, usually magnetic, with added functions.

Reduced-voltage, single-speed motor starters: Some machines or loads may require a gentle start and smooth acceleration up to full speed. In addition to load demands, power company regulations may limit the current surge or voltage fluctuation that can be imposed on the power supply during motor starting.

Many starters apply reduced voltage to motor windings; primary resistor, primary reactor, autotransformer, and solid state. Part winding and wye-delta starters can also provide reduced-voltage starting, although technically they are not reduced-voltage starters.

Multispeed motor starters: Motor windings in multispeed squirrel-cage motors may require special starters.

Starters for separate-winding two-speed motors consist of two standard three-pole starter units that are electrically and mechanically interlocked and mounted in a single enclosure. Additional units can be used for each speed. Although these are always electrically interlocked, it may not be practical to provide mechanical interlocks on more than two starters.

The starter for a consequent-pole two-speed motor requires a three-pole

ORIENTAL MOTOR®

AS SOLID AS A ROCK!

THE "NEW K" SERIES

NEW

Oriental Motor means POWERFUL & QUIET in your factory!

- **3 Phase Terminal Box Construction**
- 7 – 10 dB noise down (compared with previous motor)
- Small and High Torque
- Gearmotor Speed Range: 1 rpm to 600 rpm
- Gearmotor Torques to 87 lb-in Available
- Electronic Brake Available

The Cornerstone of Automation

By:
ORIENTAL MOTOR U.S.A. CORP.

HEADQUARTERS AND LOS ANGELES OFFICE:
2580 W. 237th St., Torrance, California 90505-5217 **Tel:** (310) 515-2264
SAN JOSE OFFICE:
1600 Wyatt Dr., Suite 2; Santa Clara, California 95054 **Tel: (408) 988-2655**
NEW YORK OFFICE:
369 Passaic Ave.; Fairfield, New Jersey 07004 **Tel: (201) 882-0480**
CHICAGO OFFICE:
5420 Newport Dr. Suite 51; Rolling Meadows, Illinois 60008 **Tel: (708) 577-0310**

Circle 360

NEW

Low Noise FHP Motors from your partner for automation

- 7 – 10 dB noise down! (compared with our previous motor)
- Induction Motors, Reversible Motors, Synchronous Motors, Torque Motors
- Low Noise Gearheads Available
- 1.67" sq to 4.09" sq
- High Torques in Small Packages
- 1/125 to 1/18.5 HP

The Cornerstone of Automation

By:
ORIENTAL MOTOR U.S.A. CORP.

HEADQUARTERS AND LOS ANGELES OFFICE:
2580 W. 237th St., Torrance, California 90505–5217 Tel: (310) 515-2264
SAN JOSE OFFICE:
1600 Wyatt Dr., Suite 2; Santa Clara, California 95054 Tel: (408) 988-2655
NEW YORK OFFICE:
369 Passaic Ave.; Fairfield, New Jersey 07004 Tel: (201) 882-0480
CHICAGO OFFICE:
5420 Newport Dr. Suite 51; Rolling Meadows, Illinois 60008 Tel: (708) 577-0310

Circle 361

A GIANT STEP IN PRECISION

- **Step Angle is 1.8 or 0.9 Degree**
- Size Ranges from 1.65" sq to 3.28" sq
- High Output Power
- Gearheads & Failsafe Brakes Available
- Fast Response
- Pinpoint Accuracy

The Cornerstone of Automation

By:
ORIENTAL MOTOR U.S.A. CORP.

Technical Support Line: (800) 468-3982 Pacific Time

HEADQUARTERS AND LOS ANGELES OFFICE:
2580 W. 237th St., Torrance, California 90505-5217 Tel: (310) 515-2264
SAN JOSE OFFICE:
1600 Wyatt Dr., Suite 2; Santa Clara, California 95054 Tel: (408) 988-2655
NEW YORK OFFICE:
369 Passaic Ave.; Fairfield, New Jersey 07004 Tel: (201) 882-0480
CHICAGO OFFICE:
5420 Newport Dr. Suite 51; Rolling Meadows, Illinois 60008 Tel: (708) 577-0310

Circle 362

unit and a five-pole unit. The design of the particular motor winding determines whether the fast or slow-speed connection is made by the five-pole unit.

For three-speed consequent-pole motors, a three-pole starter is used for the single-speed winding; a five-pole starter and a second three-pole starter handle the reconnectable winding. A four-speed consequent-pole motor requires two sets of three and five-pole starters.

Different power circuits are needed for delta-type multispeed motors, because currents circulate within the inactive or unconnected winding. A pair of four-pole starters is required for a two-speed motor with separate open-delta windings. Another four-pole starter is required for each speed. Thus, three and four-speed motors with open-delta windings require very complex starters.

Specific winding information is used to select the motor controls. Torque characteristics also deserve special attention to ensure selection of the proper control. Constant-horsepower motors require larger starters than either constant-torque or variable-torque motors of equal horsepower. Reversing and reduced-voltage operations can be incorporated in a multispeed motor starter.

Synchronous motor controls: Controllers for synchronous motors have four components: a three-pole starter for the ac stator circuit, a contactor for the dc field circuit, an automatic synchronizing device to control the dc field contactor, and a cage-winding protective relay to open the ac circuit if the motor operates too long without synchronizing.

Synchronous motors require ac power during both starting and running, thus the main contactor is closed when the motor is operating. The dc winding of the rotor is energized by the field contactor as the motor approaches synchronous speed. Two normally open poles on the field contactor make the connection for dc excitation, and one normally closed pole permits dissipation of induced field current (through a resistor) during any period of nonsynchronous operation.

For smooth synchronization, two conditions determine the instant that the dc field is energized: the rotor must be turning at the proper speed — usually 93 to 98% of synchronous speed, and the rotor poles must be lagging slightly behind stator poles of opposite polarity. Several synchronizing devices apply dc to the rotor field. Special relay systems can automatically close the dc contactor when the rotor reaches the proper speed and the rotor and stator poles are in proper relationship.

These relays will open if the motor falls out of step because of a momentary overload or voltage dip. Synchronous operation is automatically restored when voltage returns to normal or the overload is removed. In some cases, resynchronization may not be desirable from a safety standpoint. In such cases, the controller can be designed to disconnect power from the stator.

Out-of-step protection is provided by a conventional thermal-overload device (OSP). This device is energized whenever the motor is running without rotor field excitation. If, during the start, the motor does not synchronize within a given time period (usually 15 to 20 s) the OSP relay opens the main contactor.

If the motor pulls out of step while it is running, and does not resynchronize within the specified time, the relay will disconnect the motor. This protection is necessary because the cage winding

Controls our UMD and UPD step/motor drivers. PLC compatible or can be used stand-alone. Speeds to 100,000 steps/sec. Available off-the-shelf and backed by over a century of manufacturing excellence.

SUPER VEXTA®
By: ORIENTAL MOTOR®
ORIENTAL MOTOR U.S.A. CORP.

The Cornerstone of Automation

Head and Los Angeles Office: (310) 515-2264
San Jose Office: (408) 988-2655
New York Office: (201) 882-0480
Chicago Office: (312) 577-0310

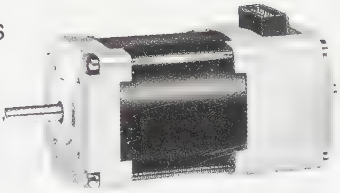
Circle 363

Announcing

NEW! FOUR SIZES OF BRUSHLESS DC MOTORS

These small brushless DC motors are virtually maintenance-free. They have outstanding torque/size ratios (see chart below). Easily controlled, they are reversible and start and stop precisely. They are engineered for intermittent or continuous duty.

Hurst's BLDC motors may be applied wherever brush servo motors are used.



A leader in brushless motor technology, we fabricate in-house many of the component parts. The result: stricter quality control.

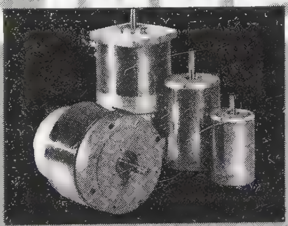
Today, get complete specifications including performance curves. Call, write or FAX Hurst Manufacturing Division, Emerson Electric Co., Box 326, Princeton, IN 47670. Telephone 812-385-2564. FAX 812-386-7504.

MODEL	TORQUE CONTINUOUS/ PEAK (oz-in)	SPEED RPM (max)	ROTOR INERTIA oz-in - sec^2 ± 10%	INPUT VOLTAGE DC (max)	K_e Volts RRPM ± 10%	K_t oz-in/Amp. ± 10%	SIZE WEIGHT
BLDC 4811-002	7.0/4.0	6000	0.0006	40	6.14	8.3	1.73″ sq x 3″ L 18 oz
BLDC 4821-002	15/85	6000	0.0015	40	6.14	8.3	2.12″ sq x 3.13″ L 25 oz
BLDC 4822-002	25/165	6000	0.003	40	6.14	8.3	2.12″ sq x 4.19″ L 35 oz
BLDC 4623-002	35/250	6000	0.0045	40	9.75	13.2	2.12″ sq x 5.25″ L 45 oz

hurst

Circle 364

BIG POWER



in small packages

Discover the impressive size/weight ratio to performance of DC Servo Motors from Inertial Motors Corp. Then see that you get more performance than you pay for:

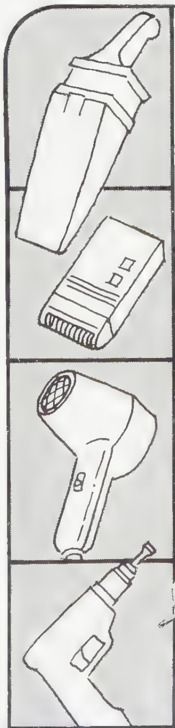
- Ultra-smooth torque, to 4,000 oz-in.
- Sizes from 2.25 to 6.3 in. dia., 0.10 to 10 HP
- Long, maintenance-free life
- Fast response to 1,000+ signals/sec. input
- Continuously repeatable, high accuracy motion control

Call, write or Fax for more technical info.

INERTIAL MOTORS CORP.
280 N. Broad St. • Doylestown, PA 18901
215-345-1010 • Fax: 215-345-0111

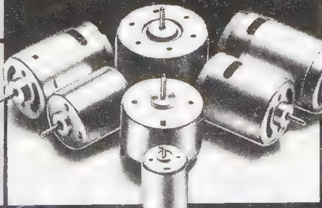
The power that puts you in control.

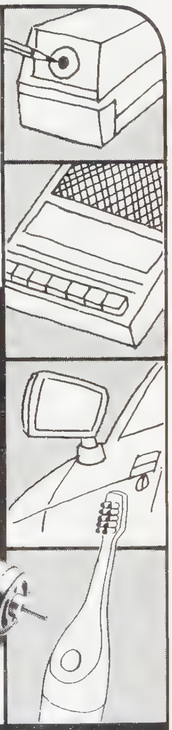
Circle 365



For every application you can think of — automotive systems/features, cordless power tools, office, audio-visual, home, personal care, cameras, hardware, pumps, etc. World's largest DC motor manufacturer offers everything you need to free your imagineering to motorize. Proven reliability, variety (over 50 models), on-time delivery, cost-effective.

Devise a star product: MOTORIZE WITH





SINCE 1954

MABUCHI MOTOR

Fax, write for Engineer's catalog; state application & voltage desired. MABUCHI MOTOR AMERICA CORP., Dept. MD2, 475 Park Avenue South, New York, NY 10016
Fax 212-532-4263 • Tel (212) 686-3622

Circle 366

REVOLUTION IN LINEAR MOTORS...

DC BRUSHLESS

The new Anoline™ Brushless Linear DC Servo Motor supplies smooth motion . . . direct. Not through a drive screw and rotary motor.

Greater Performance and Reliability

There is absolutely no physical contact between the fixed and moving parts of the motor. Conventional brushes have been replaced by electronic non-contact commutation. The elimination of carbon dust, brush sparking, and RF noise makes the Anoline Brushless ideal for clean rooms, vacuum chambers, and volatile environments.

Maintenance-free operation is guaranteed by the use of non-contact design and highly efficient rare earth magnets. The motor can provide accelerations of 4g's and velocities to 60-inches per second without backlash or stepping action.

A Motor or a System

The Anoline Brushless Motor is available in numerous models with standard travels of 2-inches to 10-feet. Use it in one of your systems. Or specify it for use in an Anorad precision positioning table from simple straightline units to multiple X-Y-Z Configurations.

Typically, an Anoline Brushless Linear DC Servo Motor is used with linear encoder or laser interferometer transducer. You can control position from .001-inch to .000001-inch depending upon the feedback device.

Specify an Anoline Brushless Linear DC Motor . . . a revolution in motor-positioning table design and application.

ANORAD CORPORATION
110 Oser Avenue, Hauppauge, NY 11788
TEL: 516/231-1995
TWX: 510-227-9894
FAX: 516-435-1612

ANORAD
THE POSITIONING SPECIALISTS

For information, circle 677

Copyright® Anorad Corporation 1986

has limited thermal capacity and will overheat in a short time at subsynchronous speed. Synchronous motors can be stopped quickly by methods similar to those used with induction motors.

Protecting motors

Motors should have protection for themselves, branch circuits, and feeder lines. Other protection, provided by fuses and circuit breakers, guards against fault conditions caused by short circuits or grounds and overcurrents exceeding locked-rotor values.

Selecting motor protectors: Line current to the motor and internal motor temperature determine motor protection. Many protectors respond to only one of these parameters. Others are both current and temperature responsive. However, use of one protector of each is not uncommon.

Current-responsive protectors are normally located in the motor or between the motor controller and the motor. In fhp and small ihp motors, temperature-responsive protectors are located within the motor and include contacts to interrupt the motor circuit. For larger motors, pilot-circuit protectors located inside the motor open the holding coil circuit of the motor-controller contactor.

Temperature-responsive protectors are assembled as integral parts of motors in order to protect against dangerous overheating from overload or failure to start. This thermal protection is provided by line-break devices or by control-circuit systems.

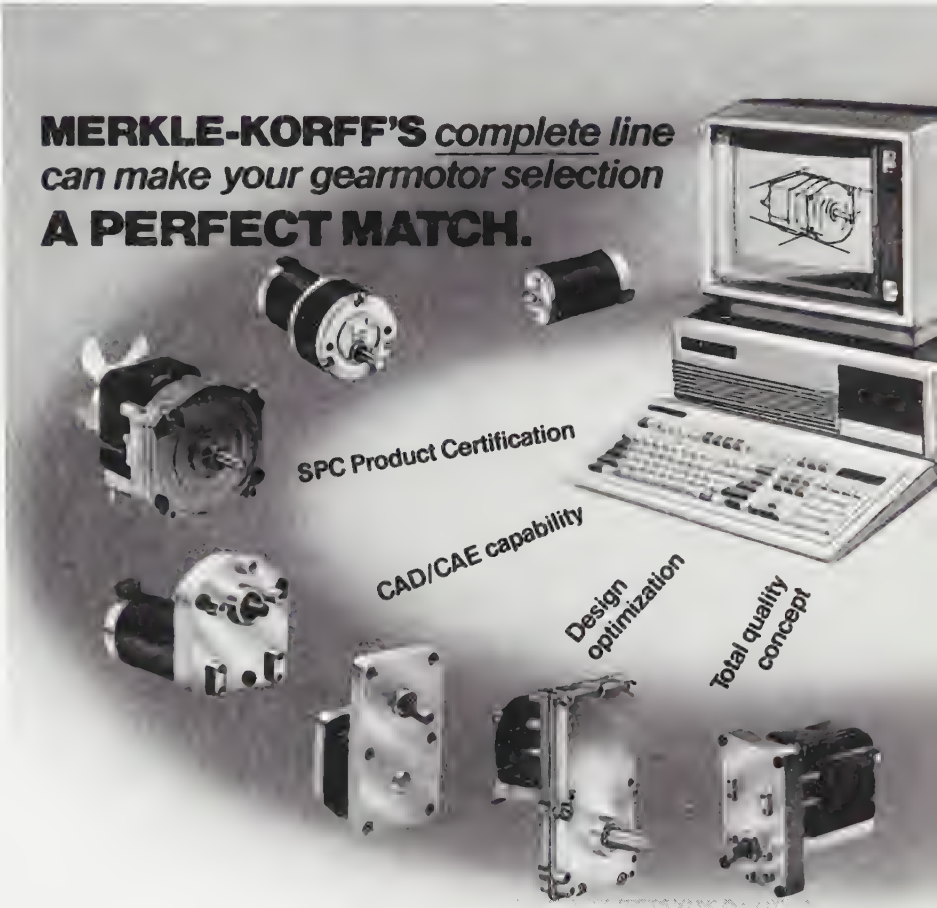
There are several suitable methods for motor protection. Current-responsive protectors provide safeguards against common causes of overload where the line current increases appreciably. However, they do not respond to overtemperature caused by hot ambient conditions or blocked ventilation. On the other hand, temperature-responsive devices protect against running overloads that produce a gradual increase in winding temperature.

Line-break thermal protectors are prevalent in smaller motors, while control-circuit systems are common on larger motors. Thermistor systems provide complete protection with small sensors in the motor. In many high-slip induction motors, the critical temperature occurs in the rotor. Temperature measurement requires slip rings and brushes, making current relays a better choice. Special motors may be designed for continuous locked-rotor current, but are still susceptible to burnout from blocked ventilation. Temperature-responsive devices are best used here.

Self-protecting starters

Self-protecting starters (SPSs) were first introduced to the U.S. in 1987. However, SPSs have been used internationally for several years. Recently, several manufacturers and private labelers have introduced new products worldwide. These starters are expected to be widely used in the U.S. during the next two years.

Several features make the SPS preferred over traditional motor controls. A self-protected starter combines contactor, overload, and short-circuit protection in one package. It is sized according to motor load current and horsepower. Generally, a small interchangeable module protects against both thermal and magnetic overload. The self-protected starter can be used in single or multiple installations and satisfy Article 430 of the National Electric Code (NEC) which addresses the safe installation of motors, circuits, and controllers.


MERKLE-KORFF'S complete line
can make your gearmotor selection
A PERFECT MATCH.
SPC Product Certification
CAD/CAE capability
Design optimization
Total quality concept

M-K's broad line of DC, Shaded Pole and Permanent Split Capacitor motors and gearmotors enables us to custom design the exact drive package you need to satisfy your specific requirements. 75+ years of experience and modern manufacturing techniques assure you of consistent product performance.

If you're using large quantities or as few as 100 gearmotors with output torque to 200 lbs. inch and speeds from 1-600 RPM, we can provide design efficiency which optimizes your design while adding quality to your product and savings to your bottom line.

Get a superior quality, performance proven AC or DC gearmotor matched to your requirements and benefit from award winning delivery, knowledgeable service and true value the perfect match provides.

Expert application engineering and prototype program offered. Integrated designs are our specialty.

Call 708-296-8800 or Fax 708-699-0832 for complete information.

MERKLE-KORFF INDUSTRIES
1776 Winthrop Drive, Des Plaines, IL 60018-1980
708-296-8800 FAX: 708-699-0832

Circle 368

Power-control equipment comprises motor control, overload and short-circuit protection, and isolation. Before SPSs, no one device could perform all these functions. They were handled by a motor starter (contactor plus overload relay) wired to either fuses or circuit breakers.

Depending on the use, location, and control sophistication required, three options were available for group or multiple motor installations. The first choice was a NEMA-rated starter. It was selected by a particular size classification that was suitable for switching motors and other kinds of loads such as capacitor banks. The second was an IEC (International Electrotechnical Commission — European Standard) starter rated by horsepower. The third choice was a horsepower-rated definite-purpose starter.

To add to the complexity, there are over six different classifications available for fuses including H, J, K, RK, RK-1, and 5. Furthermore, short-circuit protection must be coordinated

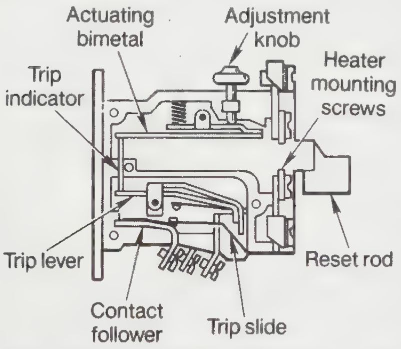
OVERCURRENT PROTECTORS

Motor burnout typically involves considerably higher-than-normal motor running current. Protectors that monitor line current include time-lag fuses, magnetic relays, and thermal relays. Except for rare cases, motor current is sensed outside the motor, often at a considerable distance.

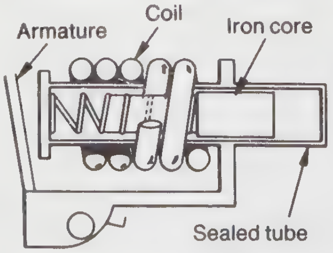
Bimetallic relays have an element made of two sheets of dissimilar metal bonded together. This composite element bends as temperature rises. The bimetal element operates a contact mechanism or a snap disc, opening the contacts.

Heaters should be selected according to motor nameplate full-load current. When selected on this basis, the trip-point of the relay is approximately 125% of full-load current in a 40°C ambient. This protection is suitable for motors with a 1.15 service factor with a 40°C rise or less (with both motor and controller at the same temperature). For motors with a service factor of 1, or with a temperature rise greater than 40°C without service-factor rating, use a heater with a rating one size smaller than would normally be selected.

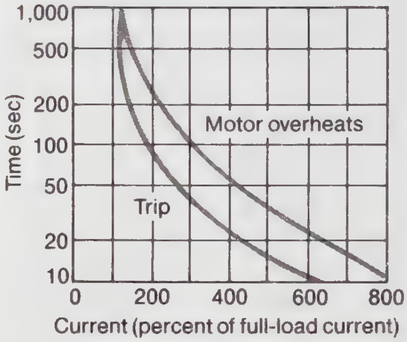
For control at an ambient constantly less than the motor ambient, decrease the motor full-load current by 8% per 10°C difference in ambient for heater selection. Conversely, for control at an ambient constantly greater than the motor ambient, correct by increasing the nameplate full-load current by 8% per 10°C difference in ambient.



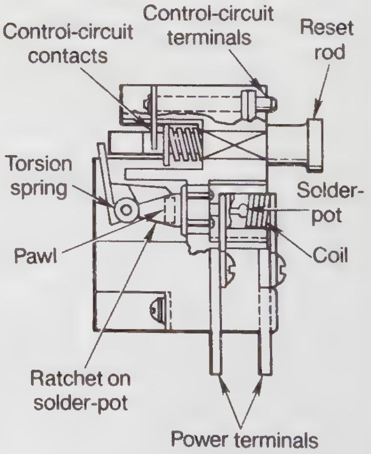
Magnetic relays, or circuit breakers, are often used because current-responsive protectors are usually located some distance from the motor. Thus, the ambient temperature at the protector may differ from that at the motor. Magnetic relays are responsive only to the magnetic field set up by the line current. A typical device has a current-carrying coil wound around a hermetically sealed, nonmagnetic tube. The tube contains a spring-biased movable iron core and a silicone damping fluid. Normal current passing through the coils is insufficient to move the iron core or attract the armature. On overloads, the magnetic field around the coil increases, pulling the iron core into the coil toward the armature end. Damping fluid impedes movement, creating a controlled time delay. Since the value of the magnetic field depends on both current and position of the iron core, an inverse time characteristic results. Thus, the magnitude of the overload determines trip time.



Thermal relays depend on heating by the line current to actuate the protection mechanism. Relays are designed to duplicate the heating of motors within the limits set by standardization.



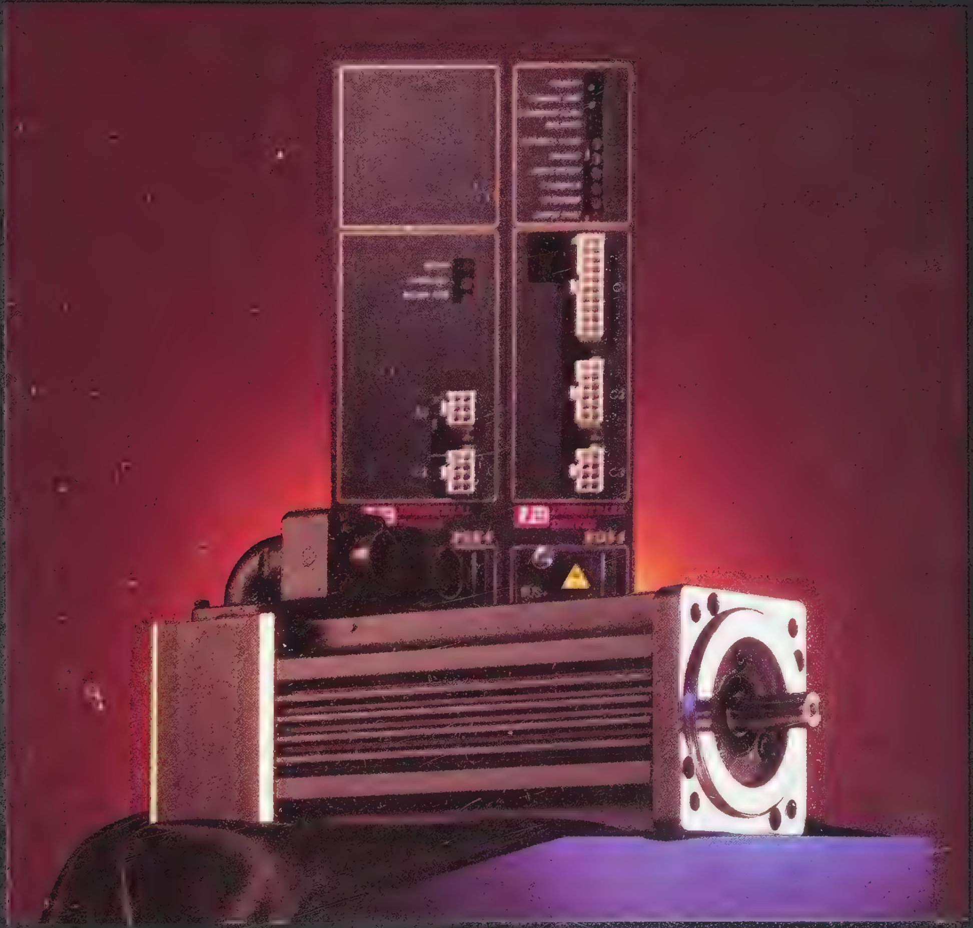
Melting-alloy relays, also called solder-pot relays, use a eutectic alloy that changes abruptly from solid to liquid at a critical temperature. When soft, the alloy releases the ratchet-and-spring mechanism, opening the relay contacts. The relay may be reset after the alloy has rehardened.



Time-lag fuses prevent sustained overcurrent, while avoiding nuisance blowouts on starting or momentary overcurrent. The National Electric Code permits selection of fuses having an operating value of 125% of rated current for class A and B motors and 115% of rated current for all other motors.

Although fuses are used to protect fhp motors, they are not generally used to protect larger motors, since their melting characteristics do not match motor heating characteristics.

The
GOLDLINE
Series



INDUSTRIAL DRIVES
A KOLLMORGEN DIVISION

201 Rock Road, Radford, Virginia 24141
(703) 639-2495 / FAX (703) 731-0847

Circle 369

INDUSTRIAL DRIVES Announce

The GOLDLINE Series — Unsurpasse

In today's uncertain economy you can still count on gold! . . .and you can count on INDUSTRIAL DRIVES' New **GOLD***LINE Series of Servomotors and Drives.*

GOLDLINE Servomotor

INDUSTRIAL DRIVES **GOLD**LINE servomotors incorporate highest energy rare earth neodymium-iron-boron magnets and excellent thermal design to provide the highest torque-to-inertia ratios and exceptional continuous torque and peak torque performance available in a compact size.

The servomotor package allows unlimited axis configurations due to the flexibility of multiple frame sizes and its lightweight rugged modular packaging. Our brushless construction makes these servomotors the right choice for extensive duty and harsh environments while supplying a full range of speed and torque capabilities.

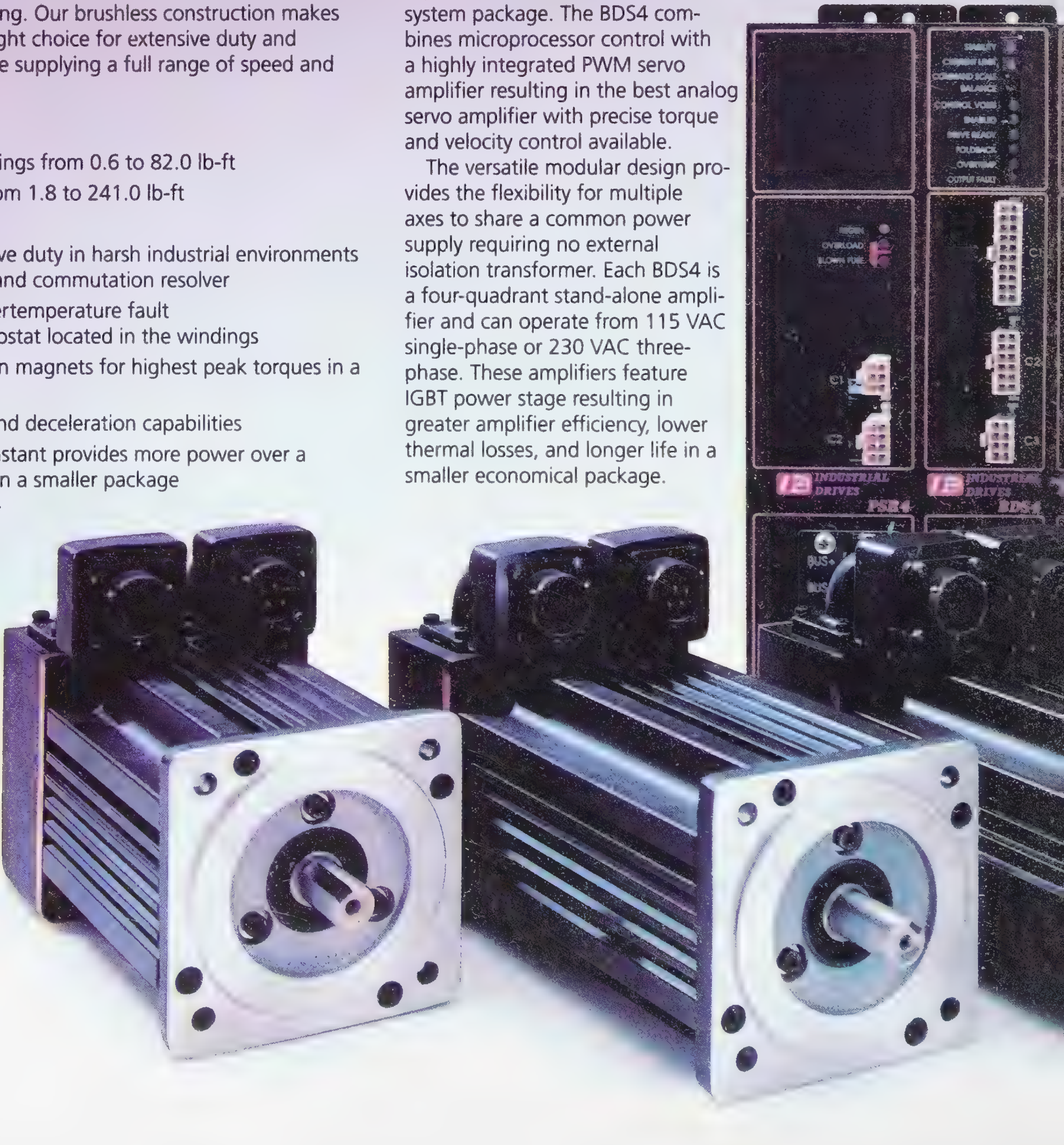
Features

- Continuous torque ratings from 0.6 to 82.0 lb-ft
- Peak torque ratings from 1.8 to 241.0 lb-ft
- Speeds to 8,000 RPM
- Well suited for extensive duty in harsh industrial environments with brushless motor and commutation resolver
- Quick detection of overtemperature fault conditions with thermostat located in the windings
- Neodymium-iron-boron magnets for highest peak torques in a compact size
- Highest acceleration and deceleration capabilities
- Long thermal time constant provides more power over a longer period of time in a smaller package
- Bearings preloaded for maximum bearing life
- Standard NEMA mountings (metric)
- Class H insulation provides in excess of 9 years of winding life under rated operating conditions
- Rugged TENV IP65 sealed construction for use in harsh environments
- Minimum torque ripple and cogging for the smoothest low-speed performance
- Options: Fail-safe brakes, encoder or resolver mounting, IP67 sealing, MS connectors, special mechanical modifications to meet customer requirements

GOLDLINE Amplifier

INDUSTRIAL DRIVES' BDS4 Amplifier is part of the **GOLD**LINE servo system package. The BDS4 combines microprocessor control with a highly integrated PWM servo amplifier resulting in the best analog servo amplifier with precise torque and velocity control available.

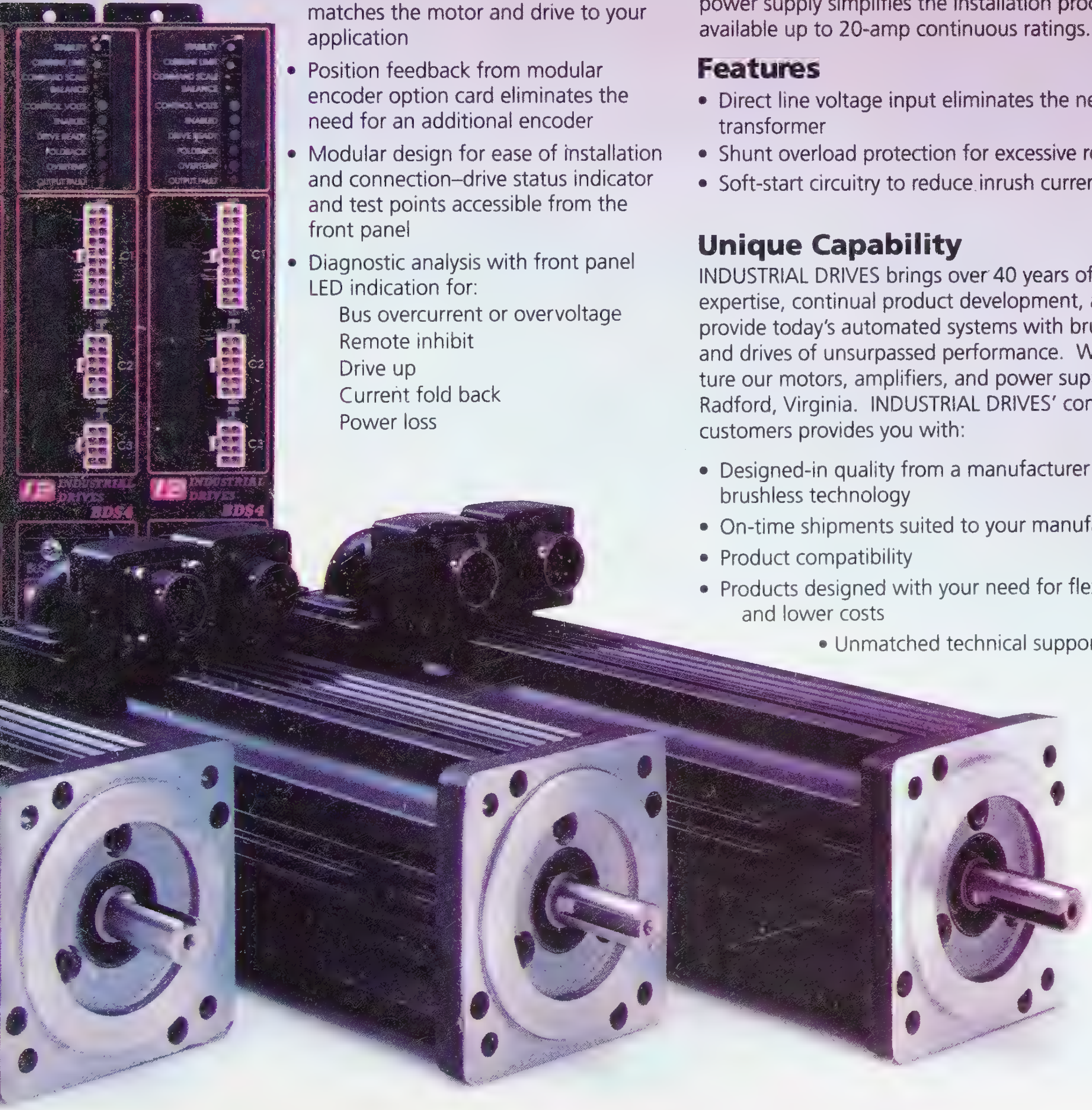
The versatile modular design provides the flexibility for multiple axes to share a common power supply requiring no external isolation transformer. Each BDS4 is a four-quadrant stand-alone amplifier and can operate from 115 VAC single-phase or 230 VAC three-phase. These amplifiers feature IGBT power stage resulting in greater amplifier efficiency, lower thermal losses, and longer life in a smaller economical package.



Servo Technology

Features

- Compact single board design minimizing interconnections and vastly increasing reliability and life
- Precise torque and velocity control
- Single and multiple axes
- Robust high bandwidth current loops to achieve the system response required–even under changing inertia loads
- Peak power ratings up to 8 KVA
- 10 kHz switching frequency reduces audible noise levels for a smooth and quiet drive
- Low cost
- Continuous power ratings up to 4 KVA
- Personality card in the amplifier matches the motor and drive to your application
- Position feedback from modular encoder option card eliminates the need for an additional encoder
- Modular design for ease of installation and connection–drive status indicator and test points accessible from the front panel
- Diagnostic analysis with front panel LED indication for:
  - Bus overcurrent or overvoltage
  - Remote inhibit
  - Drive up
  - Current fold back
  - Power loss
- Protection circuits
  - Overvoltage
  - Overtemperature
  - Short circuit on motor output
- Standard 12-bit R-to-D converter provides high resolution position and rate information from the motor's frameless resolver
- Patented microprocessor control torque angle advance feature optimizing motor performance
- Four-quadrant motor operation with regeneration



GOLDLINE Power Supply

The PSR4/5 Power Supply features multiple axis operation from one extremely compact package. The modular design of the power supply simplifies the installation process. Power supplies are available up to 20-amp continuous ratings.

Features

- Direct line voltage input eliminates the need for an external transformer
- Shunt overload protection for excessive regeneration voltage
- Soft-start circuitry to reduce inrush current

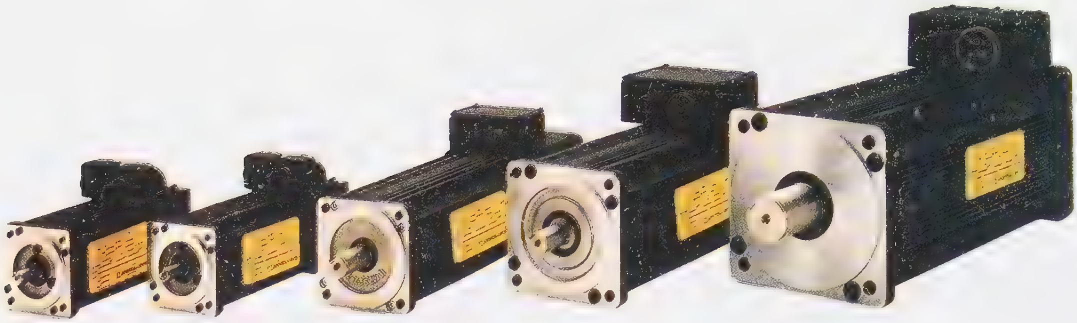
Unique Capability

INDUSTRIAL DRIVES brings over 40 years of motion control expertise, continual product development, and innovation to provide today's automated systems with brushless servomotors and drives of unsurpassed performance. We design and manufacture our motors, amplifiers, and power supplies at our plant in Radford, Virginia. INDUSTRIAL DRIVES' commitment to our customers provides you with:

- Designed-in quality from a manufacturer on the leading edge of brushless technology
- On-time shipments suited to your manufacturing schedule
- Product compatibility
- Products designed with your need for flexibility, reliability, and lower costs
- Unmatched technical support

Circle 370

GOLDLINE SERVOMOTORS



Motor	Amplifier	Cont. Torque at Stall Tc (lb-ft)	Peak (a) Torque at Stall Tp (lb-ft)	Jm x 10^4 (lb-ft-sec^2)	Cont. Power (HP)	Max. Speed (RPM)	System Rating (KVA)
120-volt Systems							
B-102-A	BDS5-103	0.61	1.64	.228	.38	3,750	.38
B-104-A	BDS5-103	1.10	2.20	.376	.55	3,050	.55
B-104-B	BDS5-106	1.10	3.12	.376	.65	3,750	.65
B-106-A	BDS5-103	1.60	3.20	.564	.60	2,100	.60
B-106-B	BDS5-106	1.60	3.12	.564	1.00	3,750	1.00
B-202-A	BDS5-103	1.66	5.05	.735	.40	1,250	40
B-202-B	BDS5-103	1.80	3.40	735	63	1,900	63
B-202-C	BDS5-106	1.80	4.16	.735	99	3,100	99
B-204-A	BDS5-103	3.30	6.95	1.275	.59	950	.59
B-204-B	BDS5-106	3.30	7.40	1.275	1.09	1,800	1.09
B-204-C	BDS5-110	3.53	7.00	1.275	2.08	3,100	2.08
B-206-A	BDS5-103	4.80	9.18	1.853	64	700	64
B-206-B	BDS5-106	4.60	9.60	1.853	1.23	1,400	1.23
B-206-C	BDS5-110	4.75	9.05	1.853	1.94	2,450	1.94
230-volt Systems							
B-102-A	BDS5-203	0.61	1.64	228	.75	7,500	75
B-104-A	BDS5-203	1.10	2.20	.376	1.10	6,100	1.10
B-104-B	BDS5-206	1.10	3.12	.376	1.30	7,500	1.30
B-106-A	BDS5-203	1.60	3.20	564	1.20	4,200	1.20
B-106-B	BDS5-206	1.60	3.12	564	2.00	7,500	2.00
B-202-A	BDS5-203	1.66	5.05	735	80	2,500	.8
B-202-B	BDS5-203	1.80	3.40	735	1.30	3,800	1.3
B-202-C	BDS5-206	1.80	4.16	735	2.00	6,200	2.0
B-204-A	BDS5-203	3.30	6.95	1.275	1.10	1,900	1.1
B-204-B	BDS5-206	3.30	7.40	1.275	2.10	3,600	2.1
B-204-C	BDS5-210	3.53	7.00	1.275	3.80	6,200	3.8
B-206-A	BDS5-203	4.80	9.18	1.853	1.30	1,400	1.3
B-206-B	BDS5-206	4.60	9.60	1.853	2.50	2,800	2.5
B-206-C	BDS5-210	4.75	9.05	1.853	3.80	4,900	3.8
B-402-A	BDS5-203	5.00	9.60	2.38	1.30	1,500	1.3
B-402-B	BDS5-206	5.20	9.75	2.38	2.90	3,000	2.9
B-402-C	BDS5-210	4.80	9.25	2.38	3.80	5,000	3.8
B-404-A	BDS5-206	9.60	18.7	4.84	2.70	1,500	2.7
B-404-B	BDS5-210	9.80	19.0	4.84	4.50	2,500	4.5
B-404-C	BDS5-220	9.70	19.2	4.84	7.30	5,000	7.3
B-406-A	BDS5-210	13.0	26.8	6.85	3.90	1,700	3.9
B-406-B	BDS5-220	13.7	28.3	6.85	7.40	3,200	7.4
B-406-C*	BDS3-230/30	12.5	24.0	6.85	9.60	5,000	9.6
B-602-A	BDS5-210	13.0	23.5	7.58	4.40	2,000	4.4
B-602-B	BDS5-220	12.8	22.8	7.58	7.70	4,000	7.7
B-604-A	BDS5-220	22.2	46.2	15.0	8.00	2,150	8.0
B-604-B*	BDS3-230/30	22.2	42.0	15.0	10.4	3,150	10.4
B-604-C*	BDS3-230/40	23.0	38.5	15.0	12.3	4,300	12.3
B-606-A	BDS5-220	33.0	66.5	22.4	8.80	1,550	8.8
B-606-B*	BDS3-230/40	33.0	57.0	22.4	13.7	3,050	13.7
B-606-C*	BDS3-230/55	33.0	55.5	22.4	14.2	4,150	14.2
B-606-D*	BDS3-230/30	31.0	53.5	22.4	11.0	2,300	11.0
B-802-A*	BDS3-230/30	31.0	61.5	36.0	10.6	2,000	10.6
B-802-B*	BDS3-230/40	30.0	60.7	36.0	12.6	2,750	12.6
B-804-A*	BDS3-230/40	59.0	109.0	62.0	14.0	1,500	14.0
B-804-B*	BDS3-230/55	58.0	112.0	62.0	18.0	2,000	18.0
B-804-C*	BDS3-230/100	58.0	138.0	62.0	21.0	3,000	21.0
B-806-A*	BDS3-230/55	80.0	152.0	93.0	20.1	1,550	20.1
B-806-B*	BDS3-230/100	82.0	154.0	93.0	24.5	3,000	24.5

* A high current version of the BDS5 will be available fourth quarter to drive these motors.

a. Peak torque values are based on peak current ratings of the standard matching amplifier. Higher current rated amplifiers can be chosen to increase peak ratings or lengthen operation in the intermittent duty zone.

Circle 371

INDUSTRIAL DRIVES

A KOLLMORGEN DIVISION

with the overload relay and the contactor to protect personnel and equipment. To ensure coordinated protection, an engineer must determine the available fault current, the corresponding fuse class, and the need for a single or dual-element device.

Choices for circuit breakers include thermal-magnetic, magnetic-only, solid-state, current-limiting, and standard or high interrupt capacity units. Thermal-magnetic devices were originally designed to protect wiring between circuit breakers and motors according to code. But they frequently had to be oversized to handle high inrush current upon start-up. The magnetic-only circuit breaker was designed to protect motors, not wire. Thus, this device provides protection more in line with the overload relay and contactor ratings.

Solid-state circuit breakers are more commonly used on motors above 100 hp for economy. Special fuses used for motor protection have built-in time delays called dual-element time-delay fuses. It is a common practice to oversize short-circuit protection for fuses or breakers. This cuts down on frequent nuisance blowing or tripping. Even the NEC allows oversizing within prescribed limits.

Self-protected starters are sized for the horsepower and full-load amperage of the motor. A typical inrush current to start a motor is six to eight times normal running current. Some new high-efficiency motors have inrush currents of eight to ten times their running current. SPS devices eliminate nuisance tripping with adjustable protection of two types. First, adjustable overload protection for full-load amperage is provided. In any case, the overload setting should not be greater than the actual full-load current. Second, a magnetic-only trip coil, which is adjustable from six to 12 times full load, compensates for a variety of inrush currents.

When sizing motors, service factor rating is a necessary consideration. Most U.S.-made motors have a service life of 1.15, meaning they will handle 115% of normal running current indefinitely without damage. A service factor of 1.0 indicates the motor will tolerate nameplate running current only. This type of motor is being used more frequently, and needs overload protection that trips faster than the traditional Class 20 overload relay.

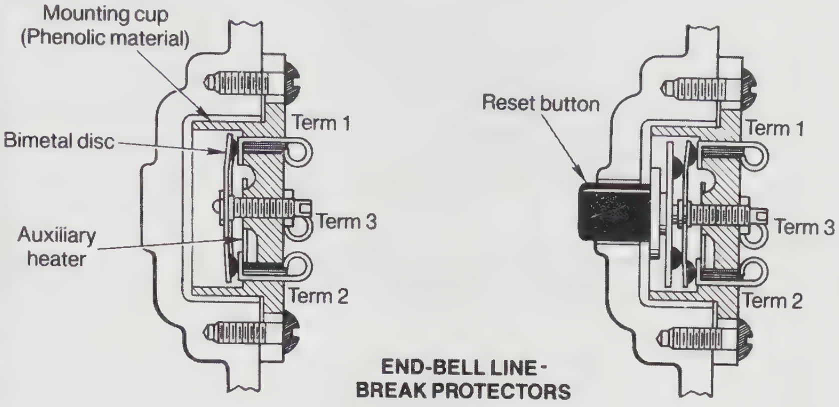
Class 10 overloads (trips within 10 sec at six times full-load motor current) for small motors work well with a 1.0 or 1.15 service factor. Some special applications with over 5 sec start-up times can cause early tripping. However, the Class 10 overload used on self-protecting starters is the preferred method of motor protection.

At full locked-rotor current, the Class 10 overload relay trips in 10 sec or less, protecting motors without creating nuisance tripping. Relays do not trip because most motors reach full operating speed in less than 5 sec. This is particularly important with the trend toward smaller motors with short start-up times. Another advantage is that overload adjustments can be sealed or locked to prevent tampering.

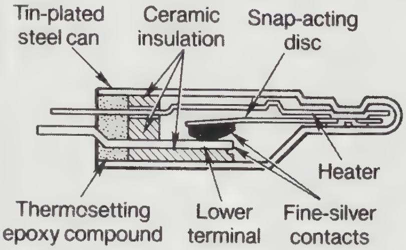
Another factor to consider is phase imbalance during brownouts or phase loss. In the event one phase drops out in IEC devices like SPSs, there is a 57% increase in current across the other

PROTECTORS

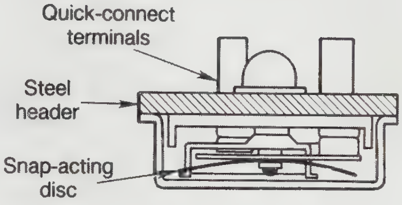
Motor temperature and current are sensed by protectors in fhp and ihp motors up to 15 hp. Most line-break protectors operate through snap-action bimetal discs with an internal series heater to provide suitable response to locked-rotor conditions. Bimetal temperature is the sum of its ambient temperature in the motor and the I^2R heating generated internally by motor current. Disc opening temperature is reached when safe motor-winding temperature is exceeded.



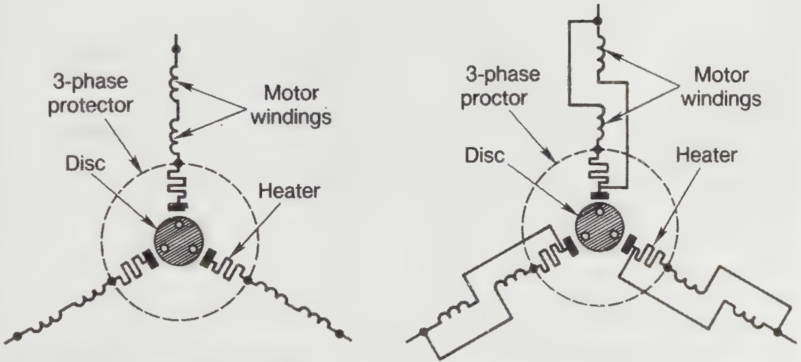
END-BELL LINE-BREAK PROTECTORS



ON-WINDING THERMAL PROTECTOR FOR FHP MOTORS

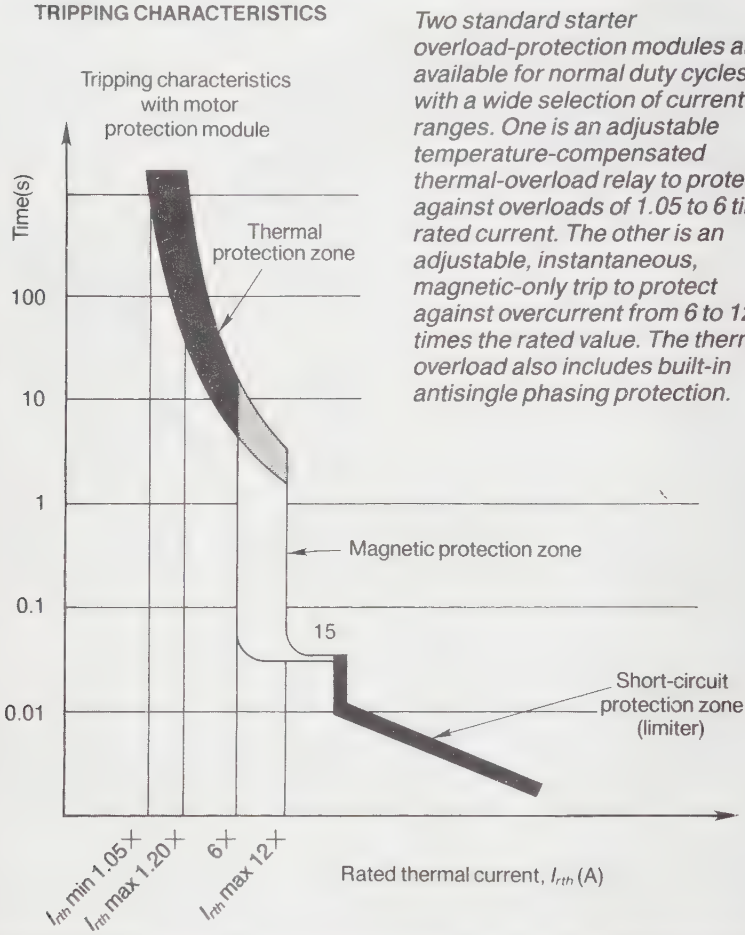


THREE-PHASE THERMAL PROTECTORS



HIGH-VOLTAGE CONNECTION **LOW-VOLTAGE CONNECTION**

Typical three-phase thermal protector used in a dual-voltage, Y-connected motor. The protector becomes the neutral of the Y. On opening, it disconnects all three phases of the motor.



Two standard starter overload-protection modules are available for normal duty cycles with a wide selection of current ranges. One is an adjustable temperature-compensated thermal-overload relay to protect against overloads of 1.05 to 6 times rated current. The other is an adjustable, instantaneous, magnetic-only trip to protect against overcurrent from 6 to 12 times the rated value. The thermal overload also includes built-in antisingle phasing protection.

phases. Time is a critical factor in protecting motors from thermal damage, so these devices contain a differential bar that increases the speed at which the overload trips. This reduces the likelihood of motor damage or burnout.

For complicated installations using PLCs or similar controls, it is best to make sure the starter can handle accessories such as shunt trips and auxiliary contacts. If field upgrades and expansions are expected later, it is also wise to make sure that spare parts will be available and that installed units can accept accessories. For example, it is easier to add auxiliary contacts to a fusible switch in the field than to add a circuit breaker which must be factory installed.

Also important is the available space devoted to motor starters, both in the panel and on the plant floor. If either is severely restricted, the choice should be for the device that saves space. The SPS will generally cut panel space by about 50% because a single device replaces separately mounted controls. This, in turn, reduces the size of the enclosure.

For example, one large control system was originally designed to house 50 motor starters. Nine motor control-center vertical sections would have been needed. But only three small panels were needed with self-protecting devices. These panels sat on an overhead walkway instead of on the shop floor, making service easier.

By comparison, another application where space was critical used 30 SPSs instead of traditional NEMA-style devices and circuit breakers. SPSs reduced the required panel size by 64% over the NEMA approach.

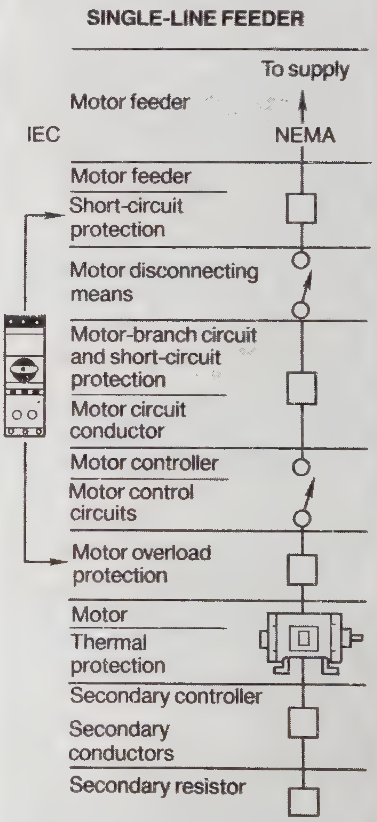
Communication or dialog with automated systems is an important feature of any control device. In most systems, this responsibility has typically been left to a programmable logic controller (PLC). Until now, many PLCs had to send full 120-V control power to starters located remotely. Status indicators only appear on the contactors and breakers themselves.

In contrast, screw-in modules enable self-protected starters to both receive controls signals from PLCs and transmit status on trip conditions or signal normal operation. The SPS can also receive direct control signals from proximity, photoelectric, limit, or push-button switches.

In fully automated systems, an additional communication function enables the device to be reset from a remote panel or central control location. A shunt-trip enables tripping by external commands.

Using SPS starters can cut installation time by 33% compared to the time needed to mount NEMA-style starters. Self-protected starters are DIN rail mounted which eliminates installation of additional protection components such as fuses and circuit breakers. And using SPSs in multiple motor-starter applications can reduce installation time as much as 80%.

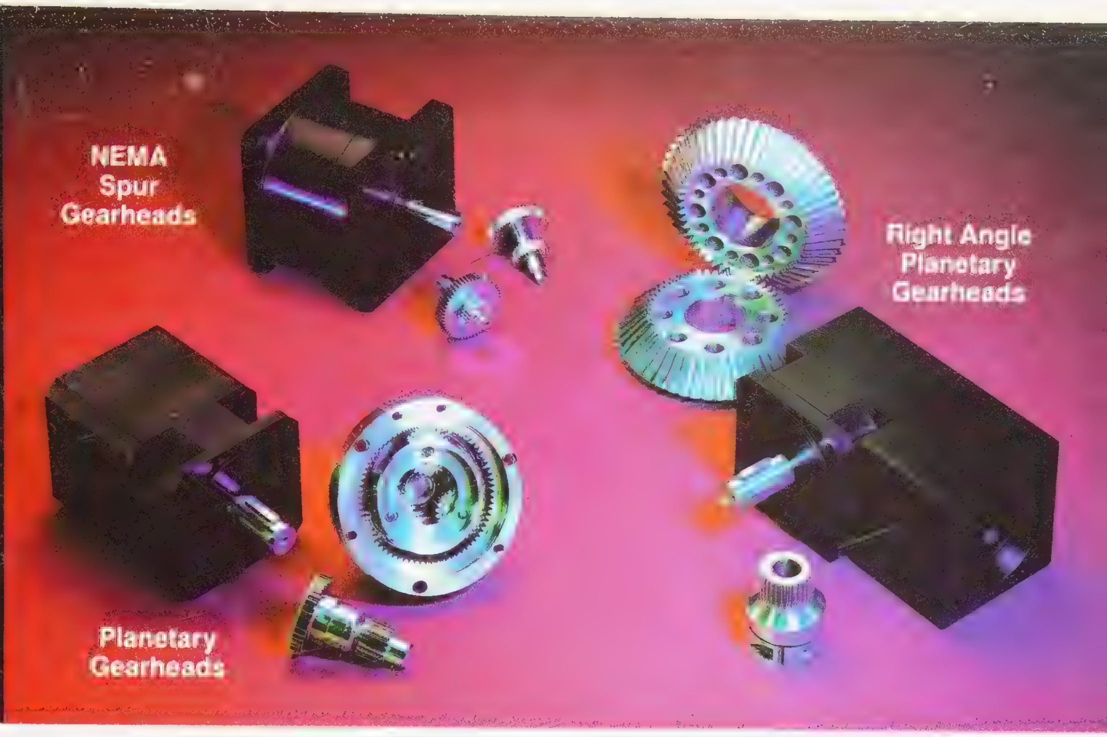
The operational design of SPSs provides a clear visual indiction of contact operation and trip status. A visual indicator on the face of the device confirms



A typical single-line feeder diagram illustrates all the elements needed to connect motors and secondary components to meet electrical codes. A typical NEMA installation requires up to six separate elements to provide these functions, but IEC self-protecting starters combine most of these functions in one package.

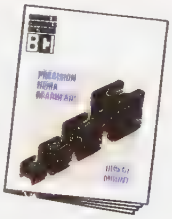
BAYSIDE Precision Gearheads

THE CHOICE IS YOURS



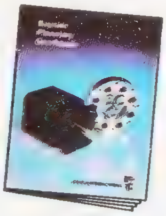
NEMA Spur Gearheads

Bayside NEMA Spur Gearheads offer high precision, low backlash, and very high efficiency, in a compact inline package. These NEMA Gearheads offer the flexibility of a complete range of ratios and sizes, provided ready-to-mount to standard NEMA-face stepper and servo motors. Bayside's Clamp-On Pinion, combined with a wide variety of different motor-mounting packages, makes it easy to attach our NEMA Spur Gearheads to many different motors.



Planetary Gearheads

Bayside Planetary Gearheads provide high torque, low backlash, and high efficiency, in a compact, inline package. With Bayside's Clamp-On Pinion, the Planetary Gearheads mount directly to the face of a wide variety of servo and stepper motors. Available in five frame sizes, and multiple ratios, Bayside Planetary Gearheads are a high performance solution to your gear reduction needs.



Right Angle Planetary Gearheads

Bayside's new Right Angle Planetary Gearheads provide the same high performance features as Bayside's Planetary Gearheads, in a space-saving right angle configuration. High efficiency, high torque, and low backlash are all provided, in five different frame sizes. Bayside's exclusive Clamp-On Pinion makes it easy to attach our Right Angle Planetary Gearheads to a wide variety of servo and stepper motors.

Bayside Gearheads mount to motors from the following companies (Partial list):

AEROTECH
ALLEN-BRADLEY
AMERICAN PRECISION
ANAHEIM AUTOMATION
BALDOR
BEI
BODINE
CLIFTON
CMC TORQUE SYSTEMS
COMPUMOTOR
CONTRAVES
EASTERN AIR DEVICES
EMERSON
FANUC
GETTYS
GIDDINGS & LEWIS
(NEXES AUTOMATION)
GME
HITACHI
HONEYWELL
INDRAMAT
INDUSTRIAL DRIVES
INFRANOR
INLAND MOTOR
INTELLICO
LEESON
MAGNETEK
MAXON
MFM
MODICON
MOOG
MTS
NYDEN
ORIENTAL MOTOR
ORMEC
PACIFIC SCIENTIFIC
PARVEX
PITTMAN
PMI
PORTESCAP
RELIANCE MOTION
CONTROL
(ELECTRO-CRAFT)
SIEMENS
SUPERIOR ELECTRIC
TOSHIBA
VICKERS
WHEDCO
YOKOGAWA
YASKAWA

Our experienced engineers are ready to answer your application questions. For application help, or for a color catalog call:

BAYSIDE CONTROLS INC. • 27 SEAVIEW BOULEVARD • PORT WASHINGTON, NY 11050
TEL: (516) 484-5353 • FAX: (516) 484-5496

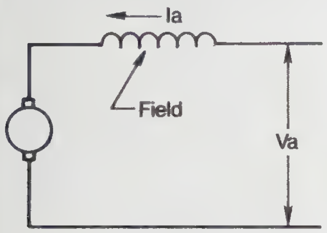
BAYSIDE CONTROLS INC.
BCI

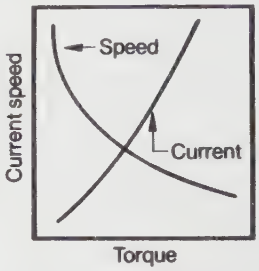
Circle 372

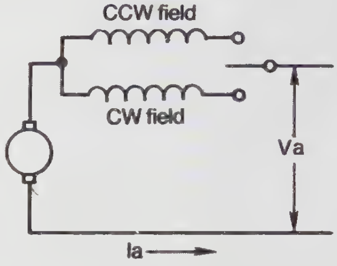
CHARACTERISTICS OF SERIES MOTORS

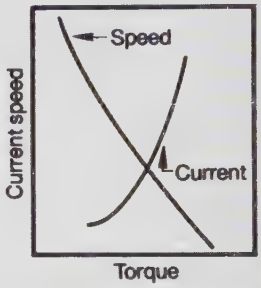
In series motors, field flux is created by coils that are electrically in series with the armature. When the motor starts, the current is at maximum. Therefore, magnetic-field density is also maximum causing a large torque. As the motor speeds up and the current reduces, field flux also becomes smaller. With no load on the motor shaft, the motor can theoretically run away because the speed rises so steeply. In small motors, brush and bearing friction and windage losses provide sufficient load to hold the terminal speed down to a safe level. However, integral-horsepower series motors should not be used on belt drives or applications where the load can drop to very low values.

Split-series motors are similar to straight-series motors except they have two oppositely wound fields. These motors can be readily reversed by switching the applied voltage from one field to the other.









that the unit is operating. In overloads, the handle rotates to a trip position. In a short circuit, the device provides an additional optical indication of the trip.

Auxiliary contacts can provide PLCs with feedback from three independent signals: contactor status , short-circuit status, and overload status. PLCs can then trigger alarms in the event of trips.

Dc motors

Industrial applications use direct current motors because the speed-torque relationship can be varied to almost any useful form — for both motor and regeneration applications in either direction of rotation. Continuous operation of dc motors is commonly available over a speed range of 8:1. Infinite range (smooth control down to zero speed) for short durations or reduced load is also common.

Dc motors are often applied where they momentarily deliver three or more times their rated torque. In emergency situations, dc motors can supply over five times rated torque without stalling (power supply permitting).

Dynamic braking (motor-generated energy is fed to a resistor grid) or regenerative braking (motor-generated energy is fed back into the dc supply) can be obtained with dc motors on applications requiring quick stops, thus eliminating the need for, or reducing the size of, a mechanical brake.

Dc motor speed can be controlled smoothly down to zero, immediately followed by acceleration in the opposite direction — without power circuit switching. And dc motors respond quickly to changes in control signals due to their high ratio of torque to inertia.

Motor types: Wound-field dc motors are usually classified by shunt-wound, series-wound, and compound-wound. In addition to these, permanent-magnet and brushless types are also available, normally as fractional-horsepower motors. Motors may be further classified for intermittent or continuous duty. Continuous-duty motors can run without an off period.

Speed control: There are two ways to adjust the speed of a wound-field dc motor. Combinations of the two are sometimes used.

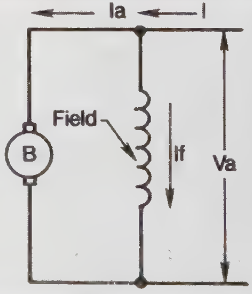
Shunt-field control: Reel drives require this kind of control in which a material is wound on a reel at constant linear speed and constant strip tension, regardless of diameter.

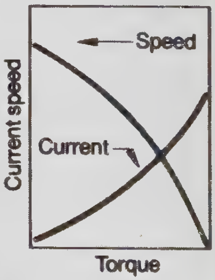
This control is obtained by weakening the shunt-field current of the motor to increase speed and to reduce output torque for a given armature current. Since the rating of a dc motor is determined by heating, the maximum

CHARACTERISTICS OF SHUNT MOTORS

Shunt-wound and stabilized shunt-wound dc motors are suitable where constant speed is needed at any preselected value or where appreciable speed range (by field control) is required. Most shunt motors operate from adjustable voltage power supplies and do not need auxiliary starting equipment.

A stabilizing winding helps prevent speed increase as the load increases at weak field settings. This winding has disadvantages in reversing applications because the relative direction of the stabilizing winding (with respect to the shunt winding) must be reversed when the armature voltage is reversed. In this case, reversing contactors must be used. Where fast reversing is needed, the stabilizing winding is left out, and the motor is designed for stable operation.

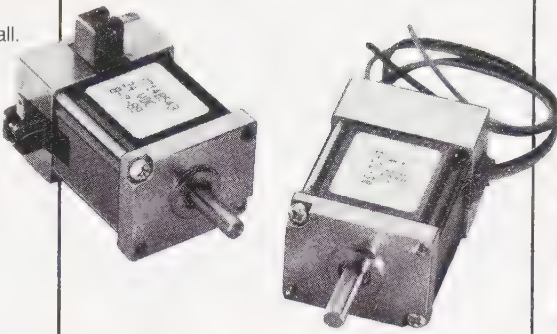




The shunt winding can be connected to the same power supply as the armature (self-excited), or it may be separately excited. The latter arrangement is widely used to change motor speed: armature voltage is varied while field voltage is held constant. Standard shunt field voltages are 100, 150, 200, 240, or 300 Vdc.

eries 8000 LO-COG® Servo Motors. 7-slot
rmatures. Voltage inputs to about 40 VDC.
lominal O.D. 1.2 in.; 3 lengths to 2.4 in. overall.
tall torques to 17 oz.-in. Mechanical time
onstants as low as 14.1 ms. (some models).

Series 9000 LO-COG® Servo Motors. 7-slot
rmatures. Voltage inputs to about 40 VDC.
Nominal O.D. 1.6 in.; 3 lengths to 2.5 in. overall.
Stall torques to 24 oz.-in. Mechanical time
constants as low as 14.7 ms. (some models).



Series 7000 Servo Motors. 13-slot armatures. 4 pole samarium cobalt fields. Voltage inputs to about 40 VDC. 1 in. x 1.25 in. cross section; lengths to 1.85 in. overall. Stall torques to 24 oz.-in. Mechanical time constants as low as 4.8 ms. (some models).

Series 9030 Servo Motors. 7-slot armatures. Voltage inputs to about 40 VDC. Nominal O.D. 1.6 in.; 3 lengths to 2.5 in. overall. Stall torques to 41 oz.-in. Mechanical time constants as low as 9.2 ms. (some models).

Series 14000 Servo Motors. 11-slot armatures. Voltage inputs to about 40 VDC. Nominal O.D. 2.13 in.; 4 lengths to 5.2 in. overall. Stall torques to 286 oz.-in. Mechanical time constants as low as 6.2 ms. (some models).

Computer tested brush-commutated DC motors

Every Pittman® motor is thoroughly evaluated ust before shipment by a sophisticated computer controlled test array which checks all significant performance parameters and records the measured values. Options for most models nclude spur and/or planetary gearheads as well as integrally mounted, metal-housed, optical encoders. We welcome the opportunity to quote value added assemblies including but not limited to pinions, timing belt pulleys, cable harnesses/RFI networks, and electric brakes. To suit your requirements, our advanced production facilities have the flexibility to permit efficient handling of small orders as well as reliable deliveries of thousands of motors per week. Contact us for complete data and application assistance. Phone (215) 256-6601. Fax (215) 256-1338.

62-C

ANADA:
ectromate Ind. Sales, Ltd.
wnsview, Ontario
.: 416-665-0221

ERMANY:
rvo Control
chnology GmbH
esbaden
.: (06121) 30 90 88

ISRAEL:
Sherman Eng. Co. Ltd
Herzliya
Tel.: 052-542853

ITALY:
SGE-Syscom s.p.a.
Milano
Tel.: (02) 6120551/2/3/4

JAPAN:
Datasonic, Inc.
Tokyo
Tel.: (03) 3342-2681

THE NETHERLANDS:
Nijkerk, Elektronika B.V.
Amsterdam
Tel.: (20) 5 49 59 69

SWEDEN:
Ostergrens Elmotor AB
Solna
Tel.: (08) 734-0610

SWITZERLAND:
Servo Control
Technology AG
Luzern
Tel.: 041/41 00 60

UNITED KINGDOM:
Servodata Ltd
Newbury, Berkshire
Tel.: (0635) 74739

© Pittman 1992

PITTMAN®
HARLEYSVILLE, PA 19438-0003 USA
A DIVISION OF PENN ENGINEERING & MANUFACTURING CORP

Circle 373

SCR-POWERED DC MOTORS

A dc motor not designed for use with SCR circuits may result in poor commutation, excessive brush sparking, sloppy speed control, and overheating.

The problems are caused by the high ripple content in the dc current. Magnitude of the ripple depends on the number of phases, rectifier connection, and amount of phase retard.

Modern dc motors are designed to overcome these problems, but older motors designed for ripple-free power frequently require smoothing reactors or derating.

Identification codes have been adopted by NEMA to indicate types of power supplies. The following letters are used for rating dc motors and for marking motor nameplates.

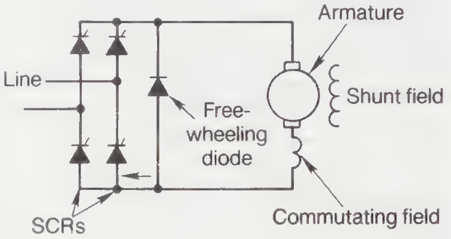
A designates a dc generator, battery, or other supply with negligible ripple.

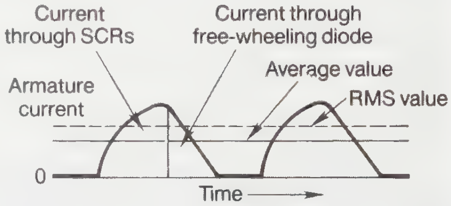
C designates a three-phase, full-wave power supply having six controlled pulses per cycle without freewheeling.

D designates a three-phase semibridge having three controlled pulses per cycle with freewheeling.

E designates a three-phase, single-way power supply having three controlled pulses per cycle without freewheeling.

K designates a single-phase, full-wave power supply having two controlled pulses per cycle with freewheeling.





permissible armature current is approximately constant over the speed range. This means that at rated current, output torque varies inversely with speed, and the motor has constant-horsepower capability over its speed range.

This system is good for only obtaining speeds greater than the base speed. A momentary speed reduction below base speed can be obtained by overexciting the field, but prolonged overexcitation overheats the motor. Also, magnetic saturation in the motor permits only a small reduction in speed for a substantial increase in field voltage.

Maximum standard speed range by field control is 3:1, and this occurs only at low base speeds. Special motors have greater speed ranges, but if the speed range is much greater than 3:1, some other control method is used for at least part of the range.

Armature-voltage control: In this method, shunt-field current is maintained constant from a separate source while the voltage applied to the armature is varied. The speed is proportional to the counter emf, which is equal to the applied voltage minus the armature circuit IR drop. At rated current, the torque remains constant regardless of the speed (since the magnetic flux is constant) and, therefore, the motor has constant torque capability over its speed range.

Horsepower varies directly with speed. Actually, as the speed of a self-ventilated motor is lowered, it loses ventilation and cannot be loaded with quite as much armature current without exceeding the rated temperature rise.

Selection: Choosing a dc motor and associated equipment for a given application requires consideration of several factors.

Speed range: If field control is to be used, and a large speed range is required, the base speed must be proportionately lower and the motor size must be larger. If speed range is much over 3:1, armature voltage control should be considered for at least part of the range. Very wide dynamic speed range can be obtained with armature voltage control. However, below about 60% of base speed, the motor should be derated or used for only short periods.

Speed variation with torque: Applications requiring constant speed at all torque demands should use a shunt-wound motor. If speed change with load must be minimized, a regulator, such as one employing feedback from a tachometer, must be used.

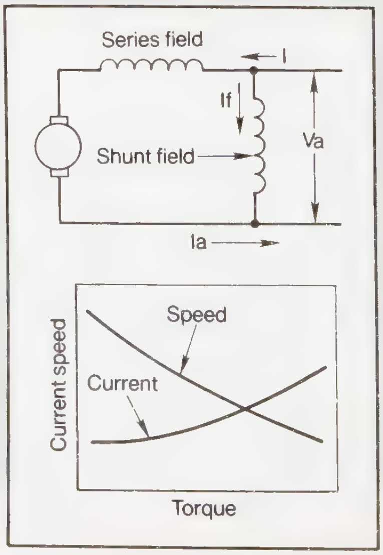
When speed must decrease as the load increases, compound or series-wound motors may be used. Or, a power supply with a drooping volt-ampere curve could be used with a shunt-wound motor.

Reversing: This operation affects power supply and control, and may af-

CHARACTERISTICS OF COMPOUND MOTORS

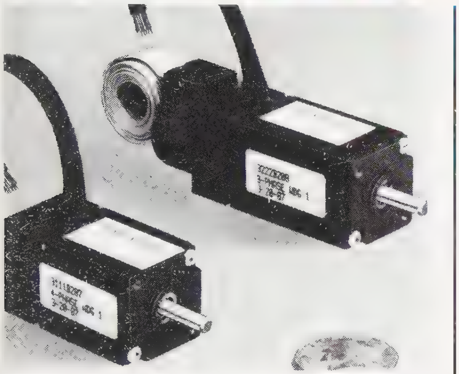
Compound-wound motors combine both series and shunt fields. At no load there is so little current in the series field that speed is determined by the shunt field alone. At higher loads, speed depends on the sum of the two fields. Thus, speed reduction is similar to that of a series motor. A compound-wound motor should be specified by the full-load speed and the speed at one other point (usually at no load).

High starting torques and fairly flat speed-torque characteristics at rated load typify compound motors. However, polarity of both the shunt and series field, or the armature, must be switched to reverse rotation. Because of the elaborate circuits needed to control compound motors, only large bidirectional motors are built. Occasionally, large blower and fan motors are slightly compounded to improve starting characteristics.



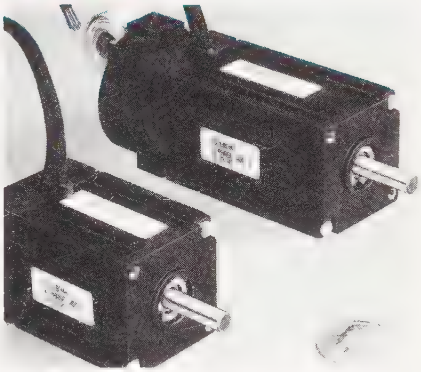
elcom®

Demonstrably superior brushless servo motors



Series 3000 30mm sq. frame size; lengths of 55.2 and 65.4mm. At 7,200 rpm, longest motor develops 1/15 hp, continuous duty, with normal heat sink.

Series 4000 40mm sq. frame size; lengths of 67.8, 75.3, and 83.0mm. At 7,200 rpm, longest motor develops 1/6 hp, continuous duty, with normal heat sink.



Series 5000 50mm sq. frame size; lengths of 77.4, 90.1, and 102.8mm. At 7,200 rpm, longest motor develops 1/3 hp, continuous duty, with normal heat sink.

- Samarium cobalt rotor construction
- Exceptional thermal efficiency
- Negligible magnetic cogging
- Very low winding inductances
- High torque to inertia ratios
- Low mechanical time constants
- Capable of high speed operation
- Optional patented 12-step drive for minimum commutation torque ripple
- Conventional 6-step drives, digital control systems, and power supplies available from Pittman

Series 6000 65mm sq. frame size; 202mm long. Internally mounted 1,000 line, 3-channel optical encoder. At 3,600 rpm, develops 1 hp, continuous duty, with normal heat sink.

Options for Series 3000, 4000, and 5000 include optical encoders and/or planetary gearheads. Get the whole story on unique Pittman® ELCOM® electronically commutated servo motors by calling (215) 256-6601. Fax (215) 256-1338.

61-C

CANADA:
Electromate Ind. Sales, Ltd.
Downsview, Ontario
Tel.: 416-665-0221

GERMANY:
Servo Control
Technology GmbH
Wiesbaden
Tel.: (06121) 30 90 88

ISRAEL:
Sherman Eng. Co Ltd.
Herzliya
Tel.: 052-542853

ITALY:
SGE-Syscom s.p.a.
Milano
Tel.: (02) 6120551/2/3/4

JAPAN:
Datasonic, Inc
Tokyo
Tel.: (03) 3342-2681

THE NETHERLANDS:
Nijkerk, Elektronika B.V.
Amsterdam
Tel.: (20) 5 49 59 69

SWEDEN:
Ostergrens Elmotor AB
Solna
Tel.: (08) 734-0610

SWITZERLAND:
Servo Control
Technology AG
Luzern
Tel.: 041/41 00 60

UNITED KINGDOM:
Servodata Ltd
Newbury, Berkshire
Tel.: (0635) 74739

© Pittman 1992

PITTMAN®
HARLEYSVILLE, PA 19438-0003 USA
A DIVISION OF PENN ENGINEERING & MANUFACTURING CORP

Circle 374

fect brush adjustment, if the motor cannot be stopped for switching before reverse operation. In this case, compound and stabilizing windings should not be used, and a suitable armature-voltage control system should supply power.

Duty cycle: Direct current motors are seldom used on drives that run continuously at one speed and load. Motor size needed may be determined by either the peak torque requirement or heating.

Peak torque: The peak torque that a dc motor delivers is limited by that load at which damaging commutation begins. Brush and commutator damage depends on sparking severity and duration. Therefore, peak torque depends on the duration and frequency of occurrence of the overload. Peak torque is often limited by the maximum current that the power supply can deliver.

Motors can commutate greater loads at low speed without damage. NEMA standards specify that dc machines must deliver at least 150% rated current for 1 min at any speed within rated range, but most motors do much better.

Heating: Temperature is a function of ventilation and electrical/mechanical losses in the machine. Some losses, such as core, shunt-field, and brush-friction losses are independent of load, but vary with speed and excitation.

The best method to predict operating temperature is to use thermal capability curves available from the manufacturer. If curves are not available, temperature can be estimated by the power-loss method. This method requires a total losses vs. load curve or an efficiency curve.

For each portion of the duty cycle, power loss is obtained and multiplied by the duration of that portion of the cycle. The summation of these products divided by the total cycle time gives the average power loss. The ratio of this value to the power loss at the motor rating is multiplied by the rated temperature rise to give the approximate temperature rise of the motor when operated on that duty cycle.

Coreless dc motors

The development of moving-coil or coreless motors dates back to the middle 1930s. But it wasn't until the early 1960s that they were produced economically enough to gain wide acceptance.

Major advantages of coreless motors include very low inertia, low mechanical time constant, and high efficiency. Because the core is ironless, its low mass allows more rapid acceleration and deceleration than any other class of dc motor.

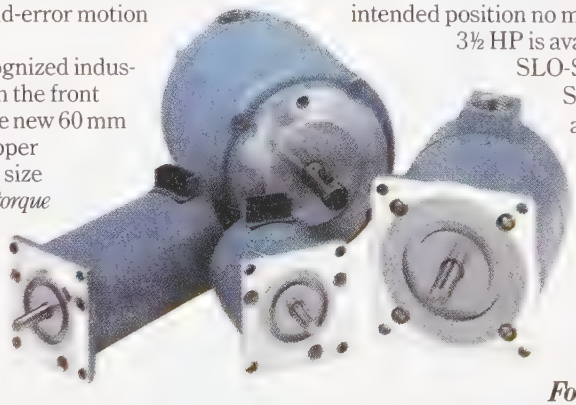
Other benefits gained by eliminating the iron core include the absence of magnetic fields acting on the laminations. This interaction in conventional motors appears as torque ripple or cogging plus a resisting torque that decreases motor efficiency. The absence of iron eliminates cogging and the coreless motor operates smoothly, even at low speeds.

Elimination of the iron core dramatically diminishes rotor inductance and resultant arcing. Commutator arcing in conventional motors is caused primarily by the release of stored energy in the armature inductance upon commutation. Excessive arcing produces electrical noise and reduces the life of brushes.

Coreless motors are classified by rotor shapes as cylindrical or disc. Cylindrical rotors are further divided into those containing inside fields or outside fields. The disc types have pancake, printed, or three-coil rotors.

The cylindrical outside-field motor has the smallest mechanical time constant. The stator is a cylindrical permanent magnet surrounded by a mild

SLO-SYN® DC Stepper Motors – quality, reliability, performance and value are the real trademarks.



Stepper motor torque gives machinery its muscle power. By increasing torque, performance and value also improve without wasting time and money on trial-and-error motion techniques.

As stepper motor originator and recognized industry leader, Superior Electric remains on the front edge of the technology. For example, the new 60 mm (NEMA Size 23D) SLO-SYN® DC Stepper Motors retain the same compact frame size yet provide up to *18 percent more typical torque* than competitive motors — with 12 percent guaranteed!

Refinements to the original patented design result in smoother operation and the new integral connector "quick-connect" feature offers substantial cost savings to the OEM.

Many standard, off-the-shelf models are available in a wide range of torque ratings, shaft configurations and frame sizes from 60 to 165 mm. Also offered are special use types such as double-end shaft, high vacuum (10^{-6} Torr.), shaft mounted encoder, viscous and Lanchester damped.

These brushless, permanent magnet motors have a full-step increment of 1.8° with accuracies of ±5% and ±3% available. Half steps and increments as small as 0.0144° are possible for microstepping. Step accuracy is noncumulative so final position is never more than selected accuracy of one full step from the intended position no matter how many steps are taken. Up to 3½ HP is available when controlled by appropriate SLO-SYN® Drives.

Specialists are ready to discuss specific applications and to recommend exact motor and drive solutions.

For free copy of SLO-SYN® Motors Catalog, call or circle reader service number.

MADE IN USA

Call 1-800-447-7171 today.

Superior Electric

DANA

Bristol, CT 06010 / (203) 582-9561
FAX: (203) 589-2136 / TLX: 96-2446

Circle 375

steel housing. The rotor is a hollow cylindrical coil wound of copper wire and located in the center of the stator. A mechanical time constant of 1 ms is not unusual for this type of motor.

Rotors are typically wound in a skewed or honeycomb pattern (also known as Faulhaber winding) to ensure that all of the core helps produce torque and smooth operation. The flux lines extend radially outward from the permanent-magnet stator through the air gap. The soft iron housing is the flux return path which allows the air gap to be extremely small, producing a high flux density.

The cylindrical inside-field motor is a similar design, but the permanent-magnet stator is located inside the hollow rotor. The motor also features a low moment of inertia, but the mechanical time constant is typically higher than the outside-field motor because of smaller stator magnets.

Coreless motor commutators and brushes are typically small, primarily because they are made of precious metals — gold, silver, platinum, or palladium. In addition, a smaller commutator has lower peripheral speed, less wear, and accounts for a smaller motor.

Outside-field motors are usually selected for high acceleration. Because of this, the rotor coils must handle a large load torque and dissipate high heat produced by peak currents. To handle the torque, manufacturers strengthen the rotor with glass epoxy. Since the rotor does not have an iron core to act as a heat sink, the housing has ports for forced air cooling.

Recent advances in coreless motor design include the replacement of Alnico with samarium-cobalt stator magnets. Also, the mechanical time constant is reduced by as much as two times with aluminum rotor wire instead of copper.

Typical accelerations for these improved motors are 150,000 rad/s^2, but rates up to 1 million rad/s^2 are possible. This greatly exceeds the 30,000 to 50,000 rad/s^2 rates available with iron-core rotor servomotors.

Brushless dc motors

Despite their superior qualities, brushless motors still run second to brush types in motion-control applications. Brushless systems are usually preferred, however, where their benefits outweigh their higher price. And they cost less than brush types in some applications when energy, maintenance, and downtime costs are included in the comparison between the two approaches.

Amplifier costs for both systems have dropped in recent years, moreover, and are forecast to drop further. Thus, the cost differential between the two approaches is an increasingly smaller percentage of total system cost. The situation has brought a large number of competitors into the market, helping to reduce prices for brushless systems. A result is that brushless motor sales have risen rapidly in the last few years. And sales of brushless motors continue to increase.

Conventional brushless motors come in a variety of configurations. The most widely used look much like brush-type motors. But brushless motors have a wound stator that surrounds a permanent-magnet rotor, an inverse arrangement from that for brush motors. And stator windings are commutated electronically rather than through a conventional commutator and brushes.

Brushless motors generally contain a three-phase winding, although some operate four phase. Brushless motors powering small fans and other constant-speed equipment are often two phase.

SLO-SYN® AC Synchronous & Gearmotors – just the right amount of automation.

Maintenance-free SLO-SYN® AC Synchronous Motors and Gearmotors are the ideal solution for designers looking for ways to improve current motion control methods or to handle any repetitive motion cycle.

Consider the features: These magnetically "geared" motors start, stop or reverse in less than 25 milliseconds. In operation, they can be stalled against a hard stop without overheating or damage to the motor or load. A simple circuit supplying DC voltage causes the motor to function as a positive electronic brake. Because of the inherent magnetic gearing, there is no need for additional external clutches. Full control requires only a single-pole, 3-position switch.

AC Synchronous Motors are available in basic shaft speeds of 72 or 200 rpm at 60 Hz and in torque ratings from 22 to 1500 oz-in (15.53 to 1059 Ncm). Because of their high torque-to-inertia ratios, these motors can reach full synchronous speeds within 5 to 25 milliseconds or 5° typical.

AC Gearmotors combine AC Synchronous Motors with a new in-line gear speed reduction assembly which minimizes space requirements and simplifies mounting. The gearbox design allows the motors to be small and compact yet powerful enough to handle torques up to 26 ft-lbs (35.3 Ncm). Speeds range from 0.6 to 200 rpm. All are rated for 100 lb (45.4 kg) axial loads and 150 lb (68 kg) radial loads so external support mechanisms and additional bearings are not needed.

Most AC Synchronous and Gearmotors are available with integral "quick-connect" connectors and mating plugs for cost savings. Special use types include hazardous location, nuclear radiation resistant, high temperature (150°C), limited vacuum (10^{-6} Torr), enclosed capacitor, double end and militarized.

Personal consultation and catalog are available on request.

1-800-447-7171

For free copy of SLO-SYN® Motors Catalog, call or circle reader service number.

Superior Electric

DANA

MADE IN USA

Bristol, CT 06010 / (203) 582-9561
FAX: (203) 589-2136 / TLX: 96-2446

Circle 375

Power for brushless motors generally is a trapezoidal ac wave form, but some of the motors operate with sine waves. Trapezoidal-powered motors develop about 10% more torque than those on sine-wave power. Sinusoidal-powered motors, however, exhibit less torque ripple and operate smoother at low speed. Thus, sinusoidal-powered motors are often used for machining, grinding, coating, and other operations calling for fine surface finishes.

Because they have no commutator, brushless motors are more efficient, need less maintenance, and can operate at higher speeds than conventional dc motors. High efficiency and small size are especially important for military, aircraft, and automotive applications, and for portable instruments and communications equipment.

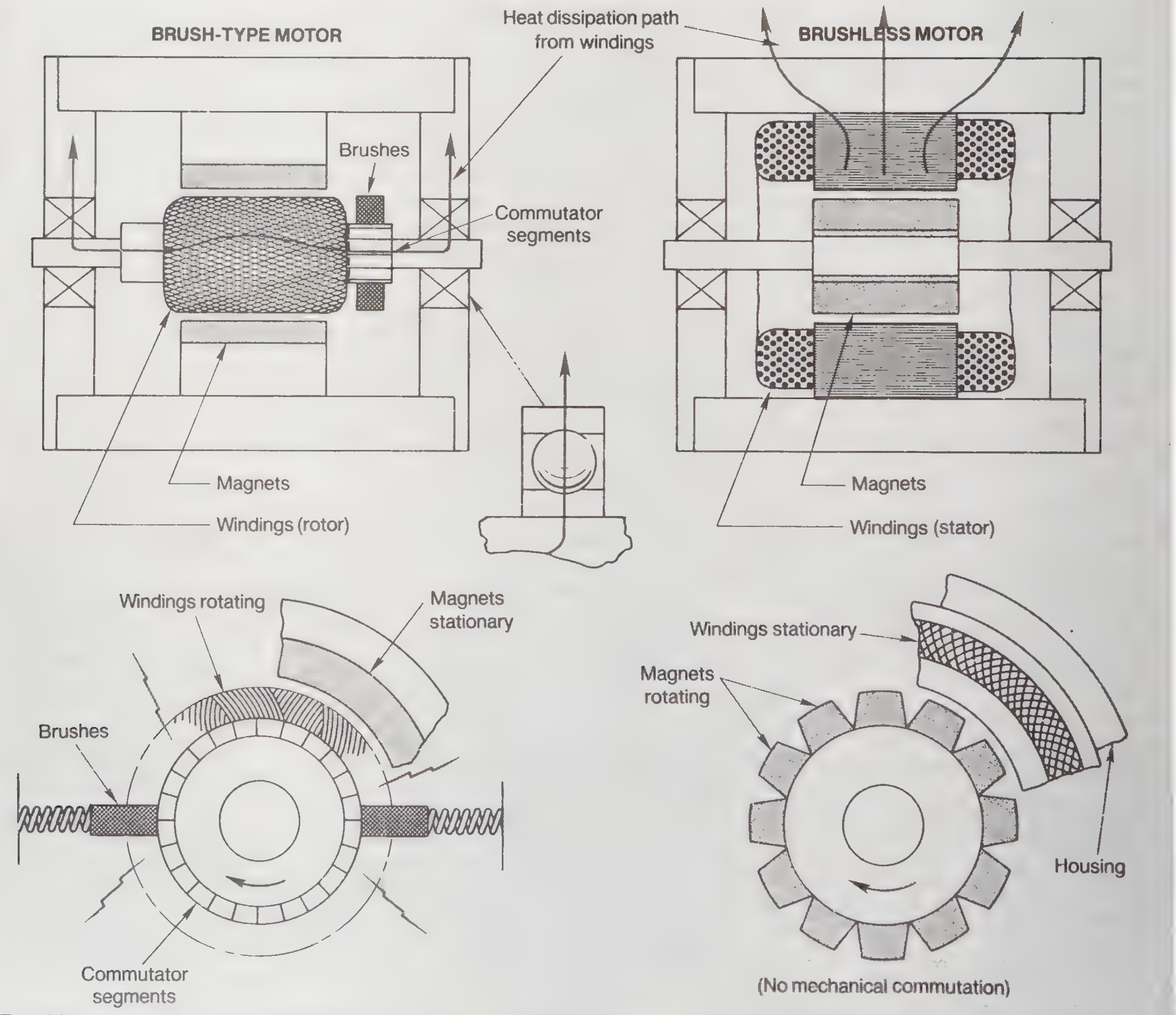
The cost of both brush-type and brushless motors likely will rise because of increasing costs for iron, steel, copper, aluminum, and magnets. The increases will be partly offset by use of neodymium-iron-boron magnets. The magnets are often more powerful than samarium-cobalt magnets and promise to be much less expensive.

Amplifiers for brushless motors are more complex than brush types and generally call for two additional solid-state power switches. These switches account for most of the cost differential between the two types. But switch cost continues to drop, in part because of increased use of MOSFET and insulated-gate type switches. Costs also are dropping for ICs used in commutation, feedback interpretation, and PWM circuits. The lower costs reduce but do not eliminate the price differential between amplifiers for the two type systems.

Limited-angle torque motors

A special type of brushless motor is called a limited-angle torquer (LAT). LATs are constrained to produce torque through a rotation angle of less than 180°. But they are widely used to

BRUSHLESS VS. BRUSH-TYPE MOTOR CONSTRUCTION



Brushless dc motors provide several benefits over brush motors. Brush commutators mechanically limit speed, generate EMI, and eventually wear out. Brush-type windings can conduct heat out only through the shaft and bearing. Brushless motors, on the other hand, are cooler. Their stators dissipate heat by direct contact with the entire motor housing. Because there are no brushes or other mechanical interfaces through which current must flow, higher currents can be used, making possible faster accelerations.

operate servovalves, direct laser mirrors, position missile-guidance radar antennas, open shutters for heat-seeking sensors, and power other systems that rotate through small angles.

The rotor in a limited-angle torquer carries field magnets, and the stator supports armature windings (similar to the construction of conventional brushless motors). LATs, however, are wound single phase, unlike conventional brushless types, which are typically wound for two or three-phase operation. Single-phase construction eliminates the need for commutation circuitry.

Conventional brushless motors can also be used for limited-angle service. But when conventional three-phase brushless motors are used as LATs, only two of the three leads are used.

Armature windings in some limited-angle torquers are embedded in slots around the inside periphery of a laminated stator, a construction similar to that used with conventional brushless motors. In another design, the armature is toroidally wound on a slotless stator. Here, some stators are laminated and others are solid.

Slot-wound LATs exhibit higher motor constant K_m than corresponding toroidally wound types. The primary reason is that a larger number of conductors can be exposed to the magnetic field.

In slot-wound LATs, heat is more easily conducted from the armature core to the outer housing than in toroidal versions, which can rely only on the mounting tabs for heat conduction. Thus, slot-wound types generally can carry heavier loads than corresponding toroidally wound motors. Slot-wound LATs, however, exhibit more torque ripple (cogging) and generate greater friction and hysteresis losses.

Cogging is essentially zero in toroidally wound LATs, a result of nonvarying reluctance path and relatively large air gap. Toroidally wound armatures, moreover, are typically molded onto the stator, which protects the windings from damage and holds then in place.

Uniform reluctance paths also make toroidally wound LATs suitable for use as limited-angle tachometers. Here, the motors are often used in pairs, one as a torquer and the second as a tachometer. The tachometer provides a reference speed signal for the motor-control circuit.

LATs produce torque through a rotation angle determined by the number of motor poles. Current of one polarity produces clockwise torque, and vice versa.

Manufacturers generally provide a theoretical torque vs. shaft-position curve. Typically, the characteristic curve for LATs is represented by the positive lobe of a cosine function; that is, $T = T_p \cos(\theta N/2)$, where θ = angle of rotation and N = number of poles. The general torque characteristic for toroidally wound motors can be represented by a similar curve, but it may also have a flat portion.

The above equation approximates torque values only for the roll-off portions of the curves. Also, the actual torque-position characteristics may vary somewhat from that shown in the curves. In particular, the curves do not reflect the effects of armature reaction, which depends on both armature current level and field magnet.

In any case, the rotational range of a LAT is generally specified in terms of a so-called excursion angle. This angle represents the difference between the rotor position that produces maximum torque and the zero-torque point on the characteristic curve.

Limited-angle torquers are generally specified with a set of factors similar to those used for conventional brushless motors. Motor performance is determined with an identical set of equations.

Limited-angle torquers are currently available in ratings from 2.8 to 1,000 oz-in. The 2.8 oz-in. LAT, a two-pole motor, has a 90° excursion angle. Its stator is 0.7 in. in diameter, weighs 1.7 oz, and is rated for 80 W peak. The 1,000 oz-in. LAT, a ten-pole motor, has an 18° excursion angle. Its stator is 1.64 in. in diameter, weighs 45 oz, and is rated for 437 W peak.

LATs that have much lower and higher torque ratings are feasible. In addition, excursion angles smaller than 18° are possible, while the maximum possible excursion is 180°.

Limited-angle torquers generally are controlled through single-phase servoamplifiers. Single-phase PWM amplifiers are widely used for the application, but LATs rated for up to a few hundred watts are more often powered by linear amplifiers.

Thermal limitations restrict linears to these low power levels. But in this range, linear amplifiers generally are simpler and less costly than PWM types.

Other configurations. Brushless motors in some cases have a cup-shaped rotor that rotates around a wound stator. The so-called inside-out motors power spindles in hard-disk drives, in certain high-speed air-conditioning and ventilation systems, and in other equipment calling for a high inertia. The high inertia makes possible very precise speed regulation.

Applications calling for high torque and low speed need brushless motors having a large number of poles — in some cases up to 64. The arrangement, often known as magnetic gearing, is an alternative to speed reducers in slow equipment and eliminates the friction, stiction, compliance, and backlash that speed-reducing systems normally exhibit.

The high pole-count motors, which are often called ring motors or ring torquers, exhibit very low torque-ripple. Sinusoidal versions of the motors exhibit even less ripple.

Pancake motors, a type of multipole motor, often power robots, transfer machines, and other equipment that needs high torque at moderate speed. The motors contain a large-diameter ring magnet, two windings, and a disk-shaped rotor. The ring magnet contains from 8 to 16 poles. Speed is constant with torque up to about 67% of peak torque, at which point speed falls.

Permanent-magnet, disc-type stepping motors can also perform like dc brushless motors. The devices exhibit high torque and low inertia, resulting in a high power rate. Eddy-current and hysteresis losses are low, permitting operation at high speed. For a given power output, disc motors are appreciably smaller and lighter than conventional types. A back-emf scheme, moreover, can provide a sinusoidal output like that of a resolver.

A permanent-magnet stepper also operates like dc brushless motors. The motors develop more torque than hybrid steppers. At speeds up to about 3,500 rpm, they produce more torque than dc servomotors. The devices contain a high-resolution position resolver that costs little and imposes no size penalty.

Magnetless versions. Variable-reluctance (VR) or switched-reluctance (SR) motors also can operate as brushless dc motors. VR motors have salient poles on a soft-iron rotor. Motor action results from interaction between the rotor poles and a rotating field set up by the stator windings. The construction yields high torque-to-inertia ratios.

VR motors cost less than corresponding permanent-magnet brushless types. And because VR types call for unidirectional current, amplifiers for them cost less than those for conventional types. The motors are increasingly used in motion-control systems that require very high torque or high horsepower — levels where the cost of magnets in conventional PM motors become excessive.

A 150-pole version of a variable-reluctance motor is widely used for powering robots and other machines calling for slow speed and precise positioning. The motors exhibit much wider bandwidths — typically over 80 Hz — than conventional motors. A 32-bit microprocessor-based adaptive controller adjusts frequency response in real time.

Another motor recently developed is generally classified as variable reluctance. But the products are sometimes thought of as hybrid permanent-magnet motors because they contain two permanent magnets mounted axially on the rotor. The motors are smaller, less costly, and operate at higher speeds than conventional dc brushless motors. They also develop up to 2,000 oz-in. torque and operate up to 5,000 rpm.

An ultrasonic motor developed in Japan employs two sheets of piezoelectric material in the armature rather than conventional windings. The sheets are energized 90° out of phase, inducing motion in the rotor. Torque levels run from 10 to 150 oz-in. at speeds up to 500 rpm.

Selecting dc motors

Sizing a dc motor to accurately meet a set of requirements can be a thankless task. Having to choose between brush-type or brushless motors can complicate the selection. Even experienced designers may sometimes overlook critical motor parameters and find problems after the system is up and running. In the worst case, starting over may be the only alternative.

Experts, however, use an expedient procedure to properly size and select dc motors. This procedure is based upon an accurate definition of the target system parameters and designer experience.

Dc motor parameters: Fortunately, several motor parameters are the same for both brush-type and brushless dc motors. One of these is motor constant, K_m. It is important but widely overlooked. It is used during motor sizing because it is a figure of merit of the motor power-to-torque ratio. K_m is proportional to the ratio of peak torque, T_p, to peak power, P_p, at stall: $K_m = T_p/\sqrt{P_p}$. K_m is also proportional to the ratio of torque sensitivity, K_t, to motor terminal resistance, R_m: $K_m = K_t/\sqrt{R_m}$.

After the required K_m has been determined, a candidate motor with this value or greater is selected from a catalog. The motor is only a candidate at this point because other factors must be determined. As the design selection progresses, some trade-offs typically take place. For example, the motor must also satisfy physical size and inertia requirements.

Winding resistance is a major factor in motor selection because it seriously affects K_m. Winding resistance and motor current produce power loss in the form of heat and motor temperature rise (TPR). These losses are also referred to as I^2R losses and directly degrade motor efficiency.

Most motor windings are copper wire which has a positive temperature coefficient. A winding temperature rise from 25 to 155°C increases wire resistance as much as 50%. Likewise, a proportional decrease in resistance occurs for temperature drops.

A three-step procedure determines the value of resistance change from a specified initial power input. First, a quality factor, F, is computed from known wattage and temperature. Second, the hot-condition wattage, W_h is calculated. Third, the quality factor is used to find final temperature rise, T_{rf}.

- Quality factor is:

$$F = \frac{1}{1 - \dfrac{(W_c)(TPR)}{(234.5 + T_{amb})}}$$

where W_c = initial power in, cold, W; TPR = motor temperature rise, °C/W; and T_{amb} = ambient temperature, °C.

- Hot wattage is $W_h = (F)(W_c)$.
- The final temperature is $T_{rf} = (W_h)(\text{TPR})$.

However, factor F is valid only over a restricted range of values for a part of the denominator, where $n = W_c(\text{TPR})/(234.5 + T_{amb})$. If $n \geqq 1$, then F is negative or infinity, signifying thermal runaway that burns open the motor. But if $n < 1$, then F is positive and the motor will stabilize at T_{rf} or less.

Core losses: Hysteresis and eddy currents in the core also make motor temperature rise. At high speeds, these losses can produce as much or more heat than I^2R losses.

Core losses depend primarily on the motor design. Design factors affecting those losses include lamination thickness, flux densities in the armature, and frequencies generated in the core that depend upon the number of poles and speed. Catalog specifications may not include core loss data, so designers must measure it by testing several sample motors. The data may also be available directly from the motor manufacturer.

Ambient temperature is the third most important factor determining motor temperature rise. A motor having a winding temperature rating of 155°C and operating in an ambient temperature of 100°C has only a 55°C allowable temperature rise. Core losses and I^2R losses quickly cut the 55°C margin under load. An ideal room ambient temperature of 25°C, by comparison, allows a 130°C temperature rise.

Use of heat sinks and air or fluid cooling moderates the temperature rise value considerably. The TPR rating of the motor per watt of input power, °C/W, is usually in the catalog or data sheet for unmounted motors. The TPR for the same motor, but mounted, TPR′ can be 25% of the unmounted value.

A conservative designer could ignore the reduced TPR in his calculations. But he would specify a motor much larger and more expensive than necessary.

Magnet properties: Dc motors use a variety of permanent-magnet materials. Early designs employed ceramic or ferrite and Alnico magnets. These materials are still widely applied, however, in automobiles and other areas where low cost as well as reliability is important. Newer designs use rare-earth samarium-cobalt and neodymium magnets.

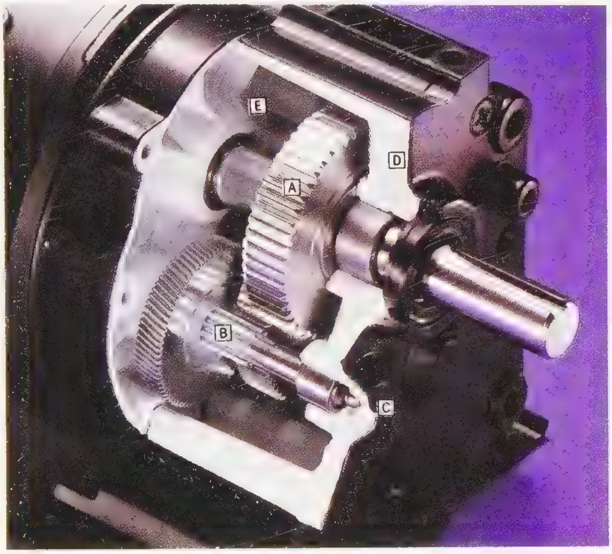
Most magnets have stable magnetic properties within the normal operating temperature range of the motor. But some magnets have a higher temperature coefficient than others. High temperature-coefficient magnets may become too weak if operated at high temperatures for extended periods. Depending on the magnetic material and slope of the motor's magnetic circuit, torque degradation may result over a wide temperature range.

Ceramic or ferrite magnets lose about 0.13%/°C of their remanence above 25°C, while rare earth and Alnico may lose only 0.03%/°C. But this loss is generally reversible if the temperature is kept within the motor rating. Colder temperatures are seldom a problem. Since the coefficient curve is linear, magnets are stronger at lower temperatures.

Some grades of rare-earth magnets are more sensitive to temperature than others. Magnets in the neodymium family may have irreversible magnetic losses under wide temperature changes. These magnets have the highest maximum-energy product (MEP), a figure of merit, of any commercial magnet now available. High MEP comes at a premium and should not be lost to temperature extremes. Neodymium magnets are continually being improved with lower temperature coefficients to make them as stable as other rare-earth grades.

SIZE FOR SIZE... THE MOST POWERFUL GEARMOTORS AND REDUCERS IN THE WORLD!

No secret. We produce higher ratings than others because we use higher quality components than our competitors do. And then, through better design, maximize the throughput those components can produce. The result is that, size for size, Bison gearmotors and reducers produce as much as 200% more torque than others! A difference that translates into much higher load handling ability and longer service life.



A Higher quality gears
We make them extra wide and then harden to give them added strength.

B Higher quality hobbing
To AGMA Class 9, next to aircraft quality. No chatter, no noise, longer life.

C Higher quality bearings
All ball and needle. No bronze sleeves masquerading. And ball thrust bearings at all pressure points!

D Higher quality housings
Precision machined cast aluminum with heavy duty reinforcing and extra thick walls.

E Higher quality lubrication
Not just a dab of grease, no periodic oiling required. Bison gearboxes are lifetime oil filled and permanently sealed.

Designed for the OEM market.

Whether standard, modified, or completely custom, Bison will design and manufacture the FHP gearmotor or reducer that will optimize your product's performance. Inputs that meet U.S., Canadian, and European voltage and frequency requirements are available. So are UL and CSA certification. Shafts are available to your specifications, as well. Machined in-house, they are available in hardened steel, and in special alloys and finishes. Airtight sealing and gasketing and high durability cord sets to resist airborne contaminants, chemicals, and moisture may be specified. So may special lubricants that allow efficient, continuous operation in temperatures as low as −60° F and as high as 165° F. And while a gloss black enamel finish is standard, finishes approved for use in food processing machinery and other regulated applications are available.

Bison is set up to serve manufacturers who use FHP gearmotors or reducers, in quantity, for commercial or military products. We produce to AGMA standards, the highest in the industry, and meet military specifications with quality assurance to MIL-I-45208A.

Doing business with the company who makes the most powerful gearmotors and reducers in the world offers you important advantages:

If you're in design engineering

1. The fact that Bison gearmotors and reducers put out far more torque in much less space allows you to design a more compact product.
2. Bison's higher performance means greater dependability. Your gearmotor choice won't come back to haunt you.
3. Bison application and design engineers are highly respected power transmission experts. They can help you insure the success of your design.
4. A large engineering group working with state-of-the-art computer assisted design means new design turnarounds in days instead of weeks.
5. Complete prototyping and testing in-house not only saves time but is capable of accurately measuring performance under close-to-actual conditions.
6. Wide-ranging line of standard component sizes that make customizing quick, convenient, and cost-effective.
7. A knowledgeable field force for on-site information and consultation.

If you're in purchasing..

1. Lower cost per inch pounds of torque means greater buying economy.
2. Higher quality components result in longer service life and fewer field failures. Especially important when conditions are tougher than anticipated.
3. Wide product line allows convenient single sourcing for a wide variety of applications.
4. Complete "drop-in" mounting interchangeability with other major gearmotor suppliers.
5. A well organized and highly responsive customer service department.
6. An excellent record for on-time deliveries.
7. A strong group of experienced field representatives for on-the-spot consultation and trouble shooting.

WE MAKE YOUR PRODUCTS GO!

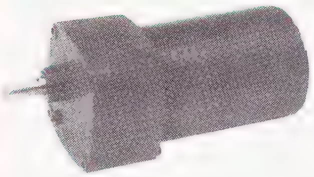
BISON
Gear & Engineering Corp.

2424 Wisconsin Avenue
Downers Grove, IL 60515
Phone: 800-AT-BISON
Fax: 708-968-3049

Circle 376

STANDARD, MODIFIED, OR COMPLETELY CUSTOM, BISON FHP GEARMOTORS AND REDUCERS OFFER IMPROVE PERFORMANCE AND EXTENDED LIFE!

PARALLEL SHAFT AND RIGHT ANGLE AC GEARMOTORS.

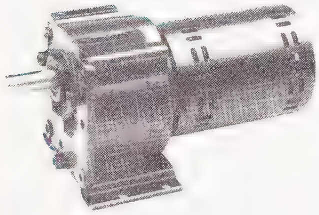


Series 100 AC
115 Volts, 60/50 Hz.
1/20 HP • 6.7″ length
1/40 HP • 7.1″ length

Series 100 AC

SPEED (RPM)	1/20 HP TORQUE (IN-LBS)	RATIO:1
320	10	5.0
240	13	6.7
165	19	9.7
124	25	12 9
85	37	18.9
63	50	25.2
44	72	36.7
33	96	49.0
22	100	71.7
17	100	95.5

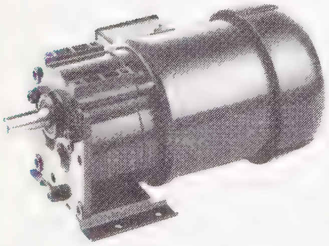
SPEED (RPM)	1/40 HP TORQUE (IN-LBS)	RATIO:1
12	100	139
9	100	185
6	100	271
5	100	362
3	100	527
2	100	702
1.5	100	1027
1	100	1369



Series 224 PSC
115 Volts, 60/50 Hz.
1/10 HP • 8.1″ length

Series 224 PSC

SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
306	20	5.4
100	58	16 5
84	82	19.8
70	97	23.4
60	113	27.7
47	123	35.4
30	185	55.9
18	282	90.9
15	265	108
9	264	176
7	263	223
4	147	397

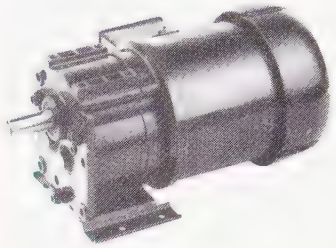


Series 242 AC
115 Volts, 60 Hz.
1/6 HP • 9.5″ length
1/12 HP • 9.5″ length

Series 242 AC

SPEED (RPM)	[illegible]	[illegible]
345	28	5.0
163	60	10.6
115	84	15.0
90	107	19.1
76	127	22.7
61	158	28.1
48	193	35.8
30	278	58.3
21	273	81.8
17	385	102
8	310	216

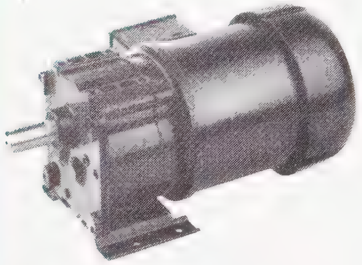
[illegible]	[illegible]	[illegible]
320	15	5.4
105	46	16.5
87	55	19.8
58	82	29.8
49	98	35.4
31	148	55.9
22	210	79.2
18	249	93.9
16	265	108
12	228	148
10	268	176
8	263	223
5	183	329



Series 242 PSC
115 Volts, 60/50 Hz.
1/6 HP • 9.5″ length

Series 242 PSC

[illegible]	[illegible]	[illegible]
330	28	5.0
156	60	10 6
110	85	15.0
86	108	19.1
73	129	22 7
59	160	28.1
46	194	35.8
28	278	58.3
20	273	81.8
16	385	102
10	204	170
8	320	216
7	144	254



Series 248 AC
115 Volts, 60 Hz.
5/8 HP • 10″ length
1/6 HP • 10.25″ length
1/12 HP • 10.25″ length

Series 248 AC

SPEED (RPM)	5/8 HP TORQUE (IN-LBS)	RATIO:
440	82	3.7
335	108	4.8
300	130	5.5
210	175	7.9
175	210	9.5
150	242	11.0
120	309	14.0
100	365	17.0
90	400	18.1
80	410	21.6
60	380	29.0
50	370	33.5
40	365	41.2

[illegible]	1/6 HP TORQUE	[illegible]
30	316	55 0

SPEED	TORQUE	[illegible]
15	289	102
8	310	216

Series 482 AC
115 & 230 Volts, 60 Hz.
1/4 HP • 14.6″ length
1/3 HP • 14.6″ length
1/2 HP • 14.6″ length
3/4 HP • 14.6″ length

Series 482 AC

SPEED	TORQUE			
282	51	67	102	154
157	93	122	185	278
136	107	141	214	321
91	160	211	320	480
60	241	318	482	722
41	385	513	720	822
33	425	567	851	1099
26	535	713	1031	1165
22	638	851	1105	
18	768	1025		
12	992			
8	973			

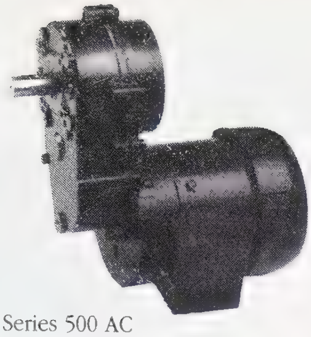
WE MAKE YOUR PRODUCTS GO!

BISON
Gear & Engineering Corp.

MANUFACTURER AGMA CERTIFIED

Every Bison gearmotor and reducer is designed to AGMA certified standards and 100% full load tested before shippi

2424 Wisconsin Avenue • Downers Grove, IL 60515 • Phone: 800-AT-BISON • Fax: 708-968-3049



Series 500 AC
115/230 Volts, 60 Hz.

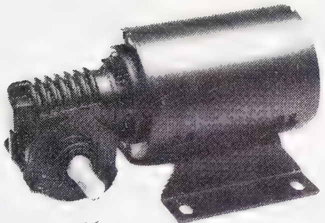
Series 500 AC

	1/3 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
92	205	18
60	310	27
30	620	55
15	1050*	114

	1/4 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
12	1100	138

	1/6 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
8	1100	199
6	1050*	261

*Output torque is gear limited.



Series 746 AC
115 Volts, 60 Hz.
1/20 HP • 7.1″ length
1/15 HP • 7.8″ length

Series 746 AC

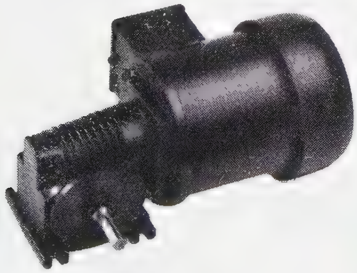
	1/20 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
315	8	5
157	15	10
105	21	15
79	25	20
54	34	30
41	42	40
27	56	60

	1/15 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
315	10	5
157	20	10
105	28	15
79	33	20
54	45	30
41	57	40
27	75	60

Series 747 AC
115/230 Volts, 60/50 Hz.
1/20 HP • 10.5″ length

Series 747 AC

	1/20 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
20	140	80.6
14	150	121
10	150	160
7	150	234
5	150	312
3.5	150	468



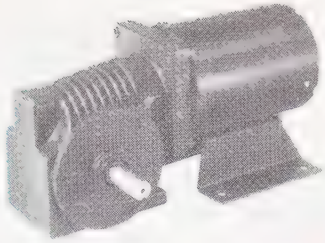
Series 750 AC
115/230 Volts, 60/50 Hz.
1/4 HP • 9″ length
1/6 HP • 9″ length

Series 750 AC

	1/4 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
319	38	5
160	62	10
80	108	20
55	130	30
36	185	45
28	140	60

	1/6 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
319	25	5
160	48	10
80	82	20
55	111	30
36	150	45
28	184	60

Note: Ratings indicated are for continuous duty. Intermittent load ratings may be increased by a factor of 1.25; occasional loads, by 1.50. For gearmotors capable of operating at both 50 and 60 Hz., torques and speeds listed are for 60 Hz. At 50



Series 754 AC
115/230 Volts, 60/50 Hz.
1/6 HP • 9″ length
1/15 HP • 8.9″ length

Series 754 AC

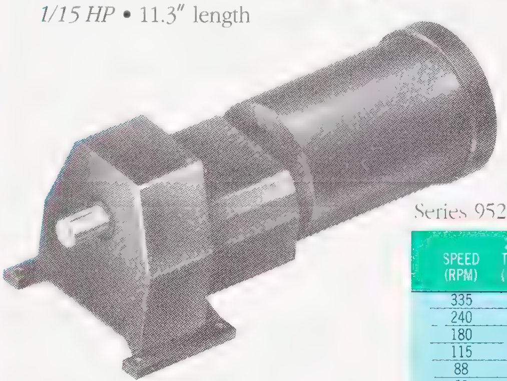
	1/6 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
319	25	5
160	48	10
80	82	20
55	111	30
36	150	45
28	184	60

	1/15 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
315	10	5
157	20	10
79	33	20
54	45	30
36	62	45
27	75	60

Series 758 AC
115/230 Volts, 60/50 Hz.
1/15 HP • 11.3″ length

Series 758 AC

	1/6 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
20	200	81
10	215	160
7.0	215	234
4.7	215	351
3.5	215	468



Series 952 AC
115/230 Volts, 60/50 Hz. & 208-230/460 Volts, 60 Hz. 3 Phase
3/4 HP • 16.4″ length
1 HP • 16.7″ length
2 HP • 17.7″ length

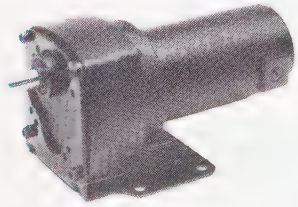
Series 952 AC

	2 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
335	300	5
240	500	7
180	650	10
115	1010	15
88	1320	20
60	1940	29
41	2720	42

	1 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
31	1800	55
21	2640	82

	3/4 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
15	2830	117
12	2600	141

PARALLEL SHAFT AND RIGHT ANGLE DC GEARMOTORS.



Series 100 DC
12 or 90 Volts
1/20 HP • 7″ length
1/40 HP • 7.8″ length

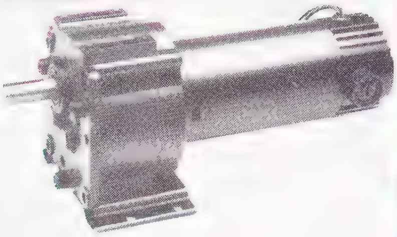
Series 100 DC

	1/20 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
359	8	5.0
269	11	6.7
185	15	9.7
139	20	12.9
95	30	18
71	40	25.2
49	55	36.7
37	74	49.0
25	100	71.7
20	100	95.5

	1/40 HP	
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
13	100	139
10	100	186
7	100	271
5	100	362
4	100	527
3	100	702
2	100	1027
1	100	1369

Circle 377

PARALLEL SHAFT AND RIGHT ANGLE DC GEARMOTORS.

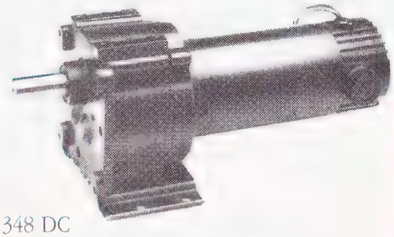


Series 300 DC
12 or 90 Volts
1/8 HP • 10.1″ length
1/20 HP • 8.4″ length

Series 300 DC

SPEED	1/8 HP TORQUE	
170	47	10.6
95	85	19.1
64	125	28.1
50	151	35.8
30	254	60.2
22	271	81.8
13	254	143
8	275	216

SPEED (RPM)	1/20 HP TORQUE (IN-LBS)	RATIO:1
109	26	16.5
60	47	29.8
32	84	55.9
20	137	90.9
18	152	101
14	192	128
12	223	148
9	260	208



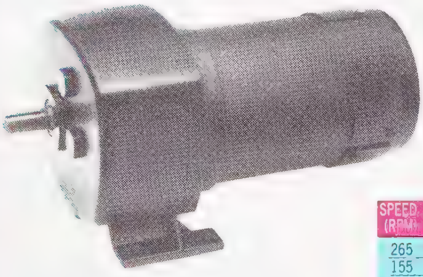
Series 348 DC
90 Volts
5/8 HP • 14.6″ length
1/3 HP • 14.5″ length
1/8 HP • 10.5″ length

Series 348 DC

SPEED (RPM)	5/8 HP TORQUE (IN-LBS)	RATIO:1
455	79	3.7
350	103	4.8
310	116	5.5
215	167	7.9
180	200	9.5
155	231	11.0
120	295	14.0
100	359	17.0
95	382	18.1
80	410	21.6

SPEED (RPM)	1/3 HP TORQUE (IN-LBS)	RATIO:1
60	304	29.0
50	352	33.5
40	365	41.2

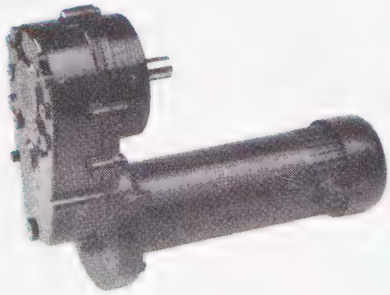
SPEED (RPM)	1/8 HP TORQUE (IN-LBS)	RATIO:1
35	196	55.0
19	380	102
9	310	216



Series 483 DC
12, 90 & 180 Volts
1/4 HP • 13.8″ length
1/3 HP • 14.8″ length
1/2 HP • 15.8″ length
3/4 HP • 17.8″ length

Series 483 DC

SPEED (RPM)	TORQUE (IN-LBS) 1/4 HP	1/3 HP	1/2 HP	3/4 HP	RATIO:1
265	56	75	113	169	6.8
155	96	128	192	288	11.6
124	120	160	240	360	14.5
100	147	198	295	443	17.8
65	220	294	440	660	27.8
44	325	434	656	976	41.1
31	460	610	917		57.9
25	575	765	1170		72.5
20	685	914	1112		86.5
14	960				131
9	1087				201



Series 500 DC
90 Volts

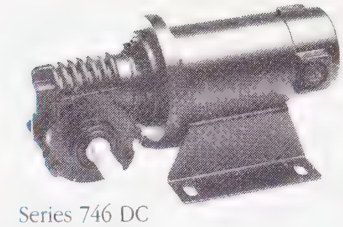
Series 500 DC

SPEED	1/3 HP TORQUE	
100	190	18
67	285	27
33	580	55
15	1045*	114

SPEED (RPM)	1/4 HP TORQUE (IN-LBS)	RATIO:1
13	1100	138

SPEED	1/6 HP TORQUE	
9	1100	199
7	1100*	251

*Output torque is gear limited.



Series 746 DC
12 & 90 Volts
1/15 HP • 7.7″ length
1/20 HP • 8.1″ length

Series 746 DC

SPEED (RPM)	1/20 HP TORQUE (IN-LBS)	RATIO
380	6	5
190	12	10
126	17	15
97	21	20
65	28	30
49	35	40
33	46	60

(RPM)	1/15 HP (IN-LBS)	RATIO
344	9	5
172	18	10
115	26	15
87	30	20
59	41	30
45	52	40
30	68	60

Series 747 DC
90 Volts
1/20 HP • 9.9″ length

Series 747 DC

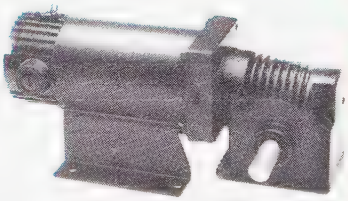
SPEED	1/20 HP TORQUE	
22	140	81
15	150	12
11	150	16
7.7	150	23
5.8	150	31
3.8	150	468

Series 750 DC
12 & 90 Volts
1/4 HP • 13.7″ length
1/8 HP • 11″ length

Series 750 DC

SPEED (RPM)	1/4 HP TORQUE (IN-LBS)	RATIO
360	19	5
180	55	10
90	95	20
60	120	30
40	160	45
30	140	60

SPEED	1/8 HP TORQUE	
360	19	5
180	29	10
90	59	20
60	72	30
40	88	45
30	102	60



Series 754 DC
12 & 90 Volts
1/8 HP • 11″ length
1/15 HP • 9.3″ length

Series 754 DC

SPEED (RPM)	1/8 HP TORQUE (IN-LBS)	RATIO
360	19	5
180	29	10
90	59	20
60	72	30
40	88	45
30	102	60

(RPM)	1/20 HP (IN-LBS)	RATIO
344	9	5
172	18	10
87	30	20
59	41	30
40	56	45
30	68	60

Series 758 DC
90 Volts
1/10 HP • 12.7″ length

Series 758 DC

SPEED (RPM)	1/10 HP TORQUE (IN-LBS)	RATI
22	200	80
11	215	16
7.7	215	23
5.1	215	35
3.8	215	46

Note: Ratings indicated are for continuous duty. Intermittent load ratings may
increased by a factor of 1.25; occasional loads, by 1.50. For gearmotors capa
of operating at both 50 and 60 Hz., torques and speeds listed are for 60 Hz.
Hz., output speed will be 5/6 of 60 Hz. speed.

PARALLEL SHAFT AND RIGHT ANGLE DC GEARMOTORS.

Series 953 DC
90 & 180 Volts
3/4 HP • 19.1″ length
1 HP • 19.6″ length
1-1/2 HP • 20.6″ length

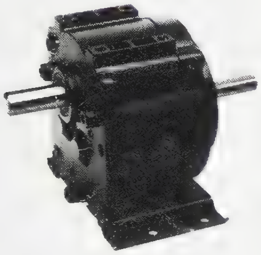
Series 953 DC

3/4 HP		
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
15	2830	117
12	2600	141

1 HP		
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
31	1770	55
21	2640	82

1-1/2 HP		
SPEED (RPM)	TORQUE (IN-LBS)	RATIO:1
335	270	5
240	380	7
180	500	10
115	760	15
88	990	20
60	1450	29
40	2040	42

REDUCERS

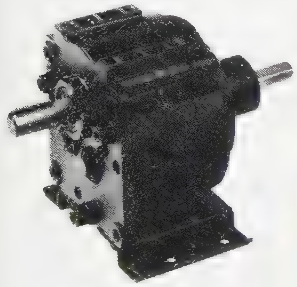


Series 250
1/8 to 1/50 HP input
• 3.7″ length

Series 250

RATIO: 1	NOMINAL SPEED* (RPM)	FULL LOAD TORQUE (IN-LBS)
16.5	104	69
19.8	87	82
23.4	74	98
29.8	62	116
29.8	58	124
35.4	49	148
43.9	39	163
55.9	31	233
79.2	22	250
100.8	17	250
107.6	16	250
119.7	14	201
149.5	12	180
162.7	11	204
178.9	10	145
201.8	9	178
243.2	7	144

*Based on 1725 RPM input.

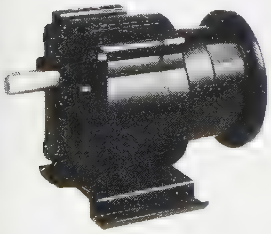


Series 250Z
1/3 to 1/2 HP input
• 5.9″ length

Series 250Z and Series 250/42 CZ

		OUTPUT TORQUE (IN-LBS.)				
RATIO: 1	NOMINAL SPEED* (RPM)	1/10 HP	1/8 HP	1/6 HP	1/4 HP	1/3 HP
12.7	136	43	53	71	107	142
19.1	90	65	81	108	161	215
22.7	76	76	96	128	190	
28.8	60	97	121	162	242	
35.8	48	119	148	200	295	
42.9	40	142	178	238		
50.8	34	167	209			
60.2	29	196	245			
64.6	27	211	260			
95.0	18	283				
133.3	13	277				
175.5	10	268				
208.0	8.3	280				
265.2	6.5	206				
329.1	5.2	183				
396.5	4.4	147				

*Based on 1725 RPM input.



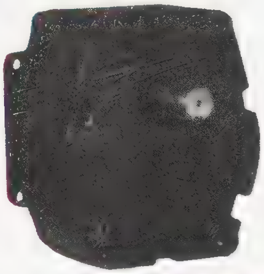
Series 250/42 CZ
Up to 1/3 HP input
• 5.75″ length

Series 480
3/4 to 1/2 HP input
• 7.7″ length

Series 480

RATIO: 1	NOMINAL SPEED* (RPM)	FULL LOAD TORQUE (IN-LBS)
6	284	167
11	157	300
13	136	347
19	91	519
29	60	781
43	40	638
55	31	606
64	27	702
95	18	1020
143	12	992
214	8	754

*Based on 1725 RPM input.

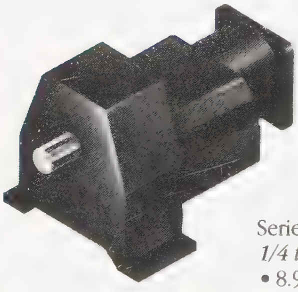


Series 881
1/4 to 1-1/2 HP input
• 8.7″ length

Series 881 (NEMA 56C input)

		OUTPUT TORQUE (IN-LBS.)					
RATIO: 1	NOMINAL SPEED* (RPM)	1/4 HP	1/3 HP	1/2 HP	3/4 HP	1 HP	1-1/2 HP
4	457	34	46	69	103	138	206
7	253	62	83	125	187	249	374
12	146	108	144	216	324	431	647
18	97	162	216	324	486	649	802**
29	60	261	348	522	783		
41	42	375	500	750	1125		
53	33	483	644	967	1128**		
79	22	721	961	1108**			
95	18	869	1017**				
143	12	992**					
211	8	974**					

*Based on 1725 RPM input.



Series 956
1/4 to 3 HP input
• 8.9″ length

Series 956 (NEMA 56C input)

		OUTPUT TORQUE (IN-LBS.)							
RATIO: 1	NOMINAL SPEED* (RPM)	1/4 HP	1/3 HP	1/2 HP	3/4 HP	1 HP	1-1/2 HP	2 HP	3 HP
5	335	45	60	90	130	175	260	350	520
7	240	60	80	120	180	240	365	485	725
10	180	80	105	160	245	325	485	645	970
15	115	125	170	250	380	505	760	1010	1515
20	88	165	220	330	495	660	990	1320	1980
29	60	240	320	485	725	970	1450	1940	
42	41	340	455	680	1020	1360	2040	2720	
55	31	445	590	885	1330	1770	2660		
82	21	660	880	1320	1980	2640			
117	15	945	1260	1885	2830				
141	12	1140	1520	2280					

*Based on 1725 RPM input.

WE MAKE YOUR PRODUCTS GO!

BISON
Gear & Engineering Corp.

AGMA MANUFACTURER CERTIFIED

Every Bison gearmotor and reducer is designed to AGMA certified standards and 100% full load tested before shipping.

2424 Wisconsin Avenue • Downers Grove, IL 60515 • Phone: 800-AT-BISON • Fax: 708-968-3049

Circle 378

SIZING A BRUSH-TYPE MOTOR

Consider a motor application that requires a peak torque, T_p, of 2.5 lb-ft at stall, and a continuous torque of 0.50 lb-ft at 200 rpm. The maximum ambient operating temperature for the motor is 50°C. Also, the maximum available supply voltage, V_s, and current, I_p, are 70 Vdc and 14 A. Space limits the motor dimensions to 4 in. diameter by 2 in. length.

To begin motor selection, the constant, K_m, is needed to find motor torque capacity. But K_m depends upon terminal resistance, R_m, and torque sensitivity, K_t — two other parameters which must be solved first.

The minimum K_t at a 14-A current limit must be calculated for the required peak torque. $K_m = T_p/\sqrt{P_p} = K_t/\sqrt{R_m}$; therefore, $K_t = T_p/I_p$. Substituting the values gives $K_t = 2.5/14 = 0.179$ lb-ft/A. K_t for the chosen motor must equal or exceed this value.

DCM 70/14 Servoamplifier specifications

PWM Frequency	20 kHz
Maximum output power	1,000 W
Maximum current output	14 A
Bus voltage input	5-95 Vdc
Efficiency	Greater than 90%
Quiescent power dissipation	Less than 10 W
Control circuit voltage input	20-32 Vdc
Command (differential)	± 10 V
Signal input impedance	10 k ohms
Tachometer range	± 50 V
Small signal bandwidth	0-6 kHz
Gain linearity	± 3%
Form factor	1.01 at 1.5 mH minimum
Operating temperature	0-85°C with derating above 60°C
± 15 Vdc output	25 mA
Size	8 in. × 4 in. × 1.75 in.
Weight	2.25 lb

QT-3102 motor specifications

Size constant	Value/Units
Peak torque rating—T_P	2.5 lb-ft
Power input, stalled at TP (25°C)—P_P	263 watts
Motor constant—K_M	0.154 lb-ft/$\sqrt{W}$
No load speed, theoretical at V_p—ωnl	77 rad/s
Electrical time constant—T_E	1.2 ms
Static friction (Max.)—T_P	0.041 lb-ft
Viscous damping coefficients:	
Zero impedance—F_O	0.032 lb-ft/rad/s
Infinite impedance—F_I	2.5×10^{-4} lb-ft/rad/s
Maximum winding temperature	155°C
Temperature rise per watt—T_{PR}	4°C/W
Ripple torque (average to peak)—T_R	5 percent
Ripple frequency—(fundamental)	39 cycles/rev
Number of poles	10
Rotor inertia—J_M	4.10×10^4 lb-ft-s^2
Motor weight	2 lb

			Winding designation			
Winding constants	Units	Tol.	A	B	C	D
Voltage, stalled at T_P (25°C)—V_P	Volts	Nom.	47.3	19.9	9.90	16.2
Peak current—I_P	Amps	Rated	5.56	13.7	29.1	18.0
Torque sensitivity—K_T	lb-ft/A	± 10%	0.450	0.182	0.086	0.139
Back EMF constant—K_B	V/rad/s	± 10%	0.610	0.247	0.116	0.188
DC resistance (25°C)—R_M	ohms	± 12.5%	8.50	1.45	0.34	0.90
Inductance—L_M	mH	± 30%	10	1.6	0.36	0.90

Next, the maximum terminal resistance, R_m, must be calculated using the given 70-V limit. Therefore, $R_m = V_s/I_p = 70/14 = 5.0\ \Omega$.

The motor constant $K_m = K_t/\sqrt{R_m} = 0.179/\sqrt{5.0} = 0.080$ lb-ft/$\sqrt{W}$. A candidate motor with a value of 0.08 lb-ft/$\sqrt{W}$ or greater is needed.

The Inland motor Model QT-3102 specs shows a K_m of 0.154 lb-ft/$\sqrt{W}$, a K_t of 0.450 lb-ft/A, and an R_m of 8.50 Ω. Several motor windings are provided for various operating conditions, but all have the same K_m. Although R_m does not meet the system specification, it remains to be seen how it influences the torque and temperature rise. All other parameters meet requirements thus far.

Next, the candidate motor must be evaluated for running torque and thermal properties. Input voltage needed to produce the demanded torque output of 0.50 lb-ft at 200 rpm is calculated. The resulting temperature rise is then computed from the input voltage and power dissipation. The final motor temperature must be less than the maximum winding temperature of 155°C.

The equation for calculating the voltage input to the dc motor under running conditions is

$$V = [(T_f + \omega_{fi} + T_l)(R_m F)/K_t] + \omega K_b$$

where V = voltage, V; T_f = friction torque, 0.041 lb-ft; f_i = viscous drag coefficient, 0.00025 lb-ft-s/rad; T_l = load torque, 0.50 lb-ft; R_m = motor terminal resistance, 8.5 Ω; K_t = torque sensitivity, 0.45 lb-ft/A; K_b = back-emf constant, 0.610 V-s/rad; ω = motor speed, 20.9 rad/s; and F = thermal heating factor, 1.5. Substituting the values gives $V = 28.23$ V.

Thermal heating factor, F, is based upon a worst-case winding temperature of 155°C as read from motor specifications. Although the actual temperature may not reach this value, it is good engineering practice to use the worst case.

Total torque, T_t, under running conditions includes friction torque, viscous drag, and load torque: $T_t = T_f + f_i + T_l = 0.546$ lb-ft. Running current, $I_r = T_t/K_t = 0.546/0.45 = 1.21$ A.

Five additional steps are needed to calculate the final motor-winding temperature. These calculations find motor input power, output power, power dissipation, and temperature rise. The temperature rise added to the ambient yields the final motor-winding temperature.

Input power, P_i, is the product of running voltage and current: $P_i = VI_r = 28.23(1.21) = 34.2$ W. Output power, P_o, is calculated from the load torque converted from lb-ft to oz-in., load speed in rpm, and a conversion factor from the horsepower-to-wattage equation: $P_o = 0.00074(96)(200) = 14.2$ W.

Power dissipated by the motor is the difference between input and output power: $P_d = 34.2 - 14.2 = 20$ W.

The worst-case winding temperature rise, T_r, is the product of motor TPR, in °C/W, and motor power dissipation: $T_r = P_d\,\mathrm{TPR} = 20(4) = 80$°C.

Final motor-winding temperature, T_f, is the sum of the ambient temperature and the temperature rise: $T_f = T_a + T_r = 50 + 80 = 130$°C. Since the allowable temperature of the motor winding is 155°C, there is a 25°C safety margin. The initial motor candidate, thus, is acceptable because all calculated parameters satisfy motor specifications.

Peak loads applied to Alnico and ceramic dc motors can degrade their magnetic properties. Alnico motors have a peak current rating which usually corresponds to a point above the knee of the B/H curve. Current exceeding this rating, caused by either a current spike or a constant dc input, are over the knee and cause permanent demagnetization. A demagnetized Alnico motor may only provide 50 to 60% of its original torque. Fortunately, rare-earth magnets are not as sensitive to demagnetization as Alnico and ceramic.

Brushless vs. brush-type: Designers planning to integrate a dc motor into a system usually work from a development specification. Constraints and limits in the specifications will largely determine whether a brush-type or a brushless motor is acceptable, based on the qualities of each.

Brush-type motors are generally used below 5,000 rpm. The actual operating speed depends upon the commutator diameter and brush material. Brush life decreases with higher commutator surface speed. Surface speed for silver-graphite brushes is usually below 650 fpm while paliney brushes are limited to only 50 fpm.

Other factors which limit brush motor life include commutator bar-to-bar voltage, brush current density, and power at the brush-commutator interface. High current and power at the brushes and commutator bar-to-bar voltage (not terminal voltage) greatly exceeding 15 Vdc produce excessive arcing. Arcing erodes brushes and commutators; wear accelerates once erosion begins.

On the other hand, electronic drives for brush motors are usually much simpler than for comparably sized brushless motors. No position sensors or electronics are required for commutation. But these components are mandatory for brushless operation. Unless

BRUSHLESS MOTOR APPLICATION

Consider a scenario where a motor operates in a space vehicle. The motor must not outgas or produce contaminates such as brush dust. Furthermore, there is no humidity to allow adequate brush filming. These constraints dictate the use of a brushless dc motor.

Assume that dynamic requirements for this motor include a peak torque of 75 oz-in. at stall and a running torque of 15 oz-in. at 8,000 rpm. Other specifications include a maximum outside motor diameter of 3.75 in. and length of 2.3 in.

The first step is to select a candidate brushless motor to meet these speed, torque, and physical size constraints. Then, a suitable driver amplifier is selected to match the motor.

The data sheet shows a model BMS-1801 brushless dc motor that has the needed physical dimensions as well as speed and torque. Next, a candidate amplifier is selected that is able to handle the back emf produced by the motor. Back emf is the product of maximum running speed in radian velocity and K_b: $V_{emf} = \omega K_b = 837.3(0.0624) = 52.25$ V. So the amplifier needs an output of 1.2 to 1.5 times 52.25 V. The initial choice is model BLM 70/12, 70 V at 12 A output capacity.

BLM 70/12 Servoamplifier spcifications

PWM Frequency	20 kHz
Maximum output power	1,080 W
Maximum current output	12 A
Bus voltage input	5-95 Vdc
Efficiency	Greater than 90%
Quiescent power dissipation	Less than 10 W
Control circuit voltage input	20-32 Vdc
Command (differential)	± 10 V
Signal input impedance	10 k ohms
Small signal bandwidth	0-5 kHz
Gain linearity	± 3%
Operating temperature	0-60°C with derating above 40° C
Encoder power	± 15 V at 25 mA
Size	8 in. × 4 in. × 2.5 in.
Weight	2.6 lb

BMS-1801 motor specification

Size constant	Value/Units
Peak torque rating—T_P	85 oz-in.
Power input, stalled at TP (25°C)—P_P	65 watts
Motor constant—K_M	10.6 oz-in./$\sqrt{W}$
Electrical time constant—T_E	2.29 ms
Static friction—T_F	2.0 oz-in.
Maximum winding temperature	155°C
Temperature rise per watt—T_{PR}	4.5°C/W
Number of poles	4
Rotor inertia—J_M	0.0150 oz-in.-s^2
Motor weight	38 oz.
Viscous damping coefficients:	
Zero impedance—F_O	0.800 oz-in./rad/s
Infinite impedance—F_I	0.002 oz-in./rad/s

			Winding designations	
Winding constants	Units	Tol.	A	B
Voltage, stalled at T_P (25°) C—V_P	volts	nom.	6.73	2.34
Peak current—I_P	A	rated	9.62	32.1
Torque sensitivity—K_T	oz-in/A	± 10%	8.84	2.65
Back EMF constant—K_B	V/rad/s	± 10%	0.0624	0.0187
DC resistance (25°C)—R_M	ohms	± 12.5%	0.700	0.073
Inductance—L_M	mH	± 30%	1.6	0.14

Two windings are provided in the candidate brushless dc motor to match several different amplifiers. Winding A is selected first. The stall voltage, V_s, is computed from given motor data and the equation:

$$V_s = I_p R_m = \frac{75.0}{8.84}(0.700) = 5.94V$$

where $I_p = T_p/K_t$; $R_m = 0.700\ \Omega$; $K_t = 8.84$ oz-in./A; and $T_p = 75.0$ oz-in. This voltage falls well within the 70-V output capability of the amplifier.

Running voltage is computed in the same way as the previous example, and is $V = 54.5$ V. The running voltage falls within specs for the amplifier output with a 1.3 margin.

Final motor winding temperature is computed from peak current, input power, output power, motor power dissipation, and temperature rise:

- $I_p = T_t/K_t = (T_f + \omega f_i + T_l)/K_t = [2 + (837.3)(0.002) + 15]/8.84 = 2.11$ A.
- Power input, $P_i = VI_p = 54.5(2.11) = 115$ W.
- Power out $P_o = 0.00074T_l$ (rpm) $= 0.00074(15)(8000) = 88.8$ W.
- Power dissipation $P_d = P_i - P_o = 115 - 88.8 = 26.2$ W.

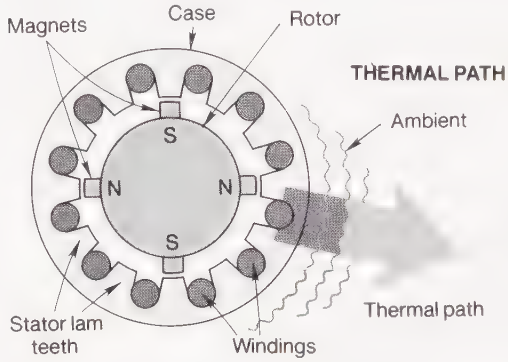
The unmounted motor temperature-rise factor, TPR, is used to determine the worst-case motor-winding temperature rise, T_r. $T_r = P_d\text{TPR} = 26.2(4.5) = 118$°C.

The allowable space ambient temperature, T_a, is the difference between the maximum motor-winding temperature, T_w, and T_r, or $T_a = 37$°C for the unmounted motor. The mounted TPR′ can be obtained from motor tests and will be much lower. The lower coefficient allows the motor to work efficiently in higher ambient temperatures.

used in a servocontrol loop, brush-type dc motors need no electronics other than a power source.

Since brushless dc motors have no commutators or brushes, brush and commutator arcing does not limit speed. Brushless dc motors are better suited for applications needing a wide speed range. Speeds from a stalled condition to more than 60,000 rpm are not unusual.

Brushless motors replace mechanical commutators with electronic switching. Brushless dc motor controllers require a position feedback signal from a sensor inside the motor. The sensor ensures that excitation to the electromagnetic armature field always leads the permanent-magnet field to produce torque. Power transistors drive the armature windings at a specified motor current and voltage level.



The thermal path for a brushless dc motor is directly from case-to-ambient. This is more efficient than a brush-type dc motor where the thermal gradient from rotor-to-ambient is much larger.

Most brushless dc motors are constructed with an outer-wound stationary armature and a rotor consisting of permanent magnets. Rotors of this type are small and have low inertias. And heat transfers more efficiently from the wound armature to ambient air in this configuration because heat dissipates from the armature core to the outer metallic housing, not conducted through the shaft like most brush-type configurations.

Motor sizing: Motor sizing takes into account all the above motor parameters and specifications. Also, the motor inertia and load must be defined for both transient and steady-state conditions. These inertia are critical since torque during acceleration exceeds torque at constant speed.

Two examples explain the sizing of dc motors for typical applications. The first example considers the selection and sizing of a brush-type dc motor. The second concerns a sterile outer-space environment requiring a brushless dc motor.

PM motors

Experts say the single most important advance in PM motor technology was the introduction of rare-earth magnetic materials in the mid-1970s. Samarium-cobalt and, to a lesser extent, neodymium has replaced Alnico and ferrite materials in many motors. Though rare-earth magnets cost more than other types, their increasingly wide acceptance over the past several years has made prices steadily decline.

Maximum-energy product (MEP) is used to indicate the relative strength of permanent magnets. Samarium-cobalt magnets typically run from 18 to 26 MGOe while neodymium ranges from 8 to 35 MGOe. In comparison, the most widely used ferrite magnets only have an MEP of 1.8 to 4.5 MGOe.

Rare-earth magnets make for small, lightweight motors with up to 50% more torque than ordinary ones having comparable dimensions. This allows a smaller rare-earth motor to do the job of a more expensive and larger conventional unit. The typical range of torque for both brush-type and brushless dc motors is from 7.0 oz-in. to 4,500 lb-ft.

Rare-earth magnets have little rotor inertia because they are light and have small radial dimensions. Flux density is also high. The torque-to-inertia ratio for rare-earth brushless motors exceeds that for conventional brushless motors by 250 to 800%. Similarly, torque-to-weight ratios surpass those of conventional types by 40 to 90%, while power-to-weight ratios are from 50 to 200% greater.

Additional improvements have been made to reduce torque ripple. There may be as much as 13 to 17% torque ripple, which causes cogging in switched brushless motors. This effect may be bad for some applications. One alternative is to use a sine-wave drive which has a theoretical ripple of zero (actually 1 to 2%). But sine-wave drivers can cost more than three times as much as switched brushless drivers because they use more complex circuitry.

However, experts say sine-wave drivers are at a point in their development that compares to switched-commutator brushless-motor drivers in the early eighties. Some predict that there will be dramatic reductions in the cost of sine-wave-driven systems over the next ten years.

Efforts to reduce cogging of brushless dc motors include shaping the back emf to better match the drive signal. Sine-wave drives need a better sine shape to reduce cogging while switched drives need a sharper trapezoid shape.

Another approach reduces ripple by doubling the number of Hall sensors in a six-step commutator. Ordinary commutators typically contain only three sensors. Doubling the number of sensors doubles the commutation cycles (electrical degrees), but keeps the mechanical angle the same without changing the number of poles. This reduces ripple torque to as low as 3 to 5% without changing either the motor or driver amplifier design. A PROM change handles the increased commutation cycles. Doubling the number of Hall encoders dramatically reduces ripple but increases motor cost. Designers now face a challenge to produce cheaper commutating encoders to offset this additional expense.

Linear dc motors

A linear dc motor, like a rotating dc motor, generates mechanical force by the interaction of current in conductors and magnetic flux provided by permanent rare-earth magnets. It is constructed of a stator assembly and a slider. The stator assembly serves as the body and contains a laminated steel structure with conductors wound in transverse slots. The slider contains one or more sets of magnets, commutation components, a bearing surface, and its body completes the magnetic flux path between the magnets.

The brush-type slider carriers two sets of brushes. One set picks up the power from a pair of copper rails, and the second set transfers power into the conductors located under the slider through commutator segments. Two of three phases are energized at any one time.

The brushless slider contains an additional set of magnets which activate Hall-effect sensors and solid-state switches to commutate the motor windings. A dc linear motor positioning system is extremely stiff, fast, and efficient. It is capable of precision accuracy to 0.1 micron and does not deteriorate with wear. It can drive loads directly, obviating the need for gears and lead screws. Its typical range of thrust and travel is 2.5 to 2,500 lb and a few inches to about 4 ft.

Brushless DC motors from Lamb have arrived

The performance and endurance of Lamb® motors will take you just about anywhere.

Lamb motors utilize electronic commutation to give you a motor that "flies" a lot further in a more compact housing.

These brushless DC motors have been engineered by Lamb with a high torque to inertia ratio for the superior stop/start capability required by many of today's high tech applications. They also minimize the problems of ripple torque, cogging effects, or demagnetization by high currents by utilizing cost effective rare earth magnets.

Only 2″ or 3.2″ in diameter, these motors have stall torque ratings up to 84 oz. in., which makes them perfect for a wide variety of applications, including tape cartridge drives, medical instruments, robots, pumps, compressors, or machine tools.

For technical data, contact AMETEK, Lamb Electric Division, 627 Lake Street, Kent, OH 44240. Tel: 216-673-3451. Fax: 216-673-8994.

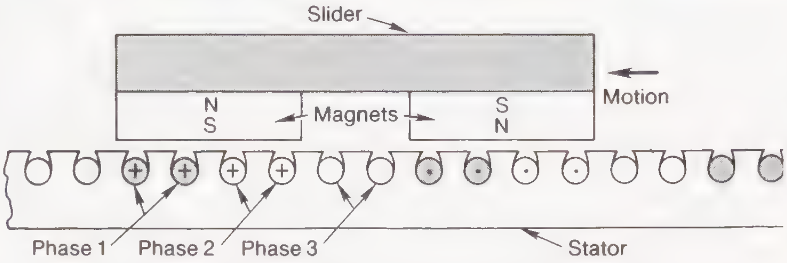
AMETEK
LAMB ELECTRIC DIVISION

Circle 379

BRUSHLESS LINEAR MOTOR

Dc linear motors generally contain a slot-type stator. Each slot typically contains numerous conductors. For simplicity, a single conductor is shown in each slot and the conductors are interconnected for three-phase operation. The phases are commutated either through brushes or electronically.

For three-phase brushless motors, a six-step commutation cycle repeats as the slider moves. As with brushless rotary motors, two of the three phases are always energized. The sketch, based on a three-phase winding requiring electronic commutation, depicts phases 1 and 2 energized. Current flows into the page under the left magnet and out of the page under the right. The interaction of the magnetic field and the current moves the slider to the left. When the motor moves two slots to the left, the commutator energizes phase 3 and cuts off phase 1. Reversing the current changes the direction of movement.



THREE-PHASE, MOVING MAGNET
BRUSHLESS LINEAR MOTOR

In brush motors only conductors in the magnetic field are energized at any one time. In contrast, all conductors in the active phase of moving-magnet brushless motors are energized. Thus, the motors are less efficient than brush types and are generally used to provide less than 3-ft travel.

Stepping motors

Stepping motors offer many advantages. Although feedback is not usually required, stepping motors are compatible with feedback signals, either analog or digital. Error is noncumulative as long as pulse-to-step integrity is maintained. A stream of pulses can be counted into a stepping motor, and its final position will be known within a small percentage of one step.

Since maximum dynamic torque occurs at low pulse rates, stepping motors can easily accelerate a load. When the desired position is reached and command pulses cease, the shaft stops and there is no need for clutches or brakes. The motor is generally left energized at a stop position. Once stopped, the motor resists dynamic movement up to the value of the holding torque. An additional feature of the PM stepping motor is that when all power is removed, it is magnetically detented in the last position. A wide range of step angles are available — 1.8 to 80°, for example — without logic manipulation. Stepping motors have inherent low velocity without gear reduction. A typical unit driven at 500 pps turns at 150 rpm. The rotor inertia is usually low. Multiple stepping motors driven from the same source maintain perfect synchronization.

But efficiency is low; much of the input energy must be dissipated as heat. Load must be analyzed carefully for optimum stepping motor performance. And inputs must be matched to the motor and load. Damping may be required when load inertia is exceptionally high to prevent oscillation.

Excitation modes: Stepping motors can be excited in different modes, depending on stator winding and desired performance.

Two phase: One entire phase (stator winding) of the motor, end-tap to end-tap is energized at a given moment in time. Input current and wattage are halved (compared to four-phase excitation), and heat dissipation is decreased. Output can be improved by as much as 10%. In the two-phase modified mode, both windings (end-tap to end-tap) are energized simultaneously. Energy input in this mode is the same as four phase, but output performance is increased by about 40%. The control is complex and costly for this mode.

Three phase: Many variable-reluctance stepping motors use three-phase windings. In modified mode, two adjoining phases are excited simultaneously and the rotor indexes to a minimum reluctance position corresponding to the resultant of the two magnetic fields. Since two windings are excited, twice as much power is required as the standard mode (one phase at a time). Output is not increased but damping is improved.

Four phase: Each half winding is regarded as a separate phase, and phases are energized two at a time. Although this mode isn't very efficient, the controller is simple. Compared to single-phase excitation, twice the input energy is required. Torque output is increased by about 40%, and maximum response rate is increased.

Five phase: Five-phase stepping motors have 10 poles rather than the 8 poles typically used in other stepping motors. Rotor-to-stator offset becomes one-fourth to one-tenth the rotor tooth pitch. A 50-tooth rotor provides a full-step of 0.72°, and a 100-tooth version produces a 0.36° full-step (0.18° half-step). The motors run at 500, 1,000, or 2,000 steps/rev with improved loaded positional accuracy and stiffer response. In addition to higher resolution, five-phase motors can produce less vibration than two to four-phase motors with virtually no resonance effects.

Variable reluctance: These stepping motors have soft iron multipole rotors and a wound stator. The number of teeth on the rotor and stator, as well as the number of winding phases, determines the step angle. Variable-reluctance motors are generally medium step-angle devices (5 to 15°) which operate at high step speeds. Torque is generally low. Rotor inertia and, thus, inertial load capacity are extremely low. Motors of this type operate at maximum pulse rates from 300 to 1,000 steps/s and have a maximum load inertia capacity of about two-thirds of rotor inertia. When excited in an overlap mode, these motors can move at half step angles and double pulse rates. The net output velocity remains the same.

Permanent magnet: PM stepping motors generally are thought of as low-torque, large step-angle devices. Torque developed by the motors is far below that for equivalent-size hybrid step motors, and step angle generally is 90 or 45°. Position resolution, moreover, is on the order of +10% of step angle, a value that generally relegates the motors to unsophisticated motion-control applications. Maximum pulse rates are for 100 steps/s for large units to 350 steps/s for small units. Rotor inertia is moderate between 5 and 75 gm-cm^2.

Rare-earth magnets make possible PM stepping motors having a large number of poles. With a suitable number of poles, PM stepping motors develop more torque than either hybrid stepping motors or dc servomotors. Speed range for the motors is less than that for dc types but much higher than that for hybrids.

Position resolution of the PM stepping motors is less than that for hybrids. But unlike hybrids, some PM stepping motors perform well in closed-loop systems.

Both cemf and iron losses are proportional to the number of poles in the motor. Thus, available torque from a PM stepping motor falls off more slowly with speed than in hybrids and more rapidly than in dc motors. The result is that PM stepping motors operate effectively at higher speeds — up to about 3,500 rpm — than hybrids but not as high as dc types. The speed range for PM stepping motors, however, suits a wide range of servo applications.

Hybrid: Hybrid stepping motors are frequently chosen for a wide variety of motion-control systems because they are easy to use. Stepping motors can maintain accuracy and reliability in open-loop mode, requiring less complex drive electronics than closed-loop servocontrollers. And absolute positioning accuracy for stepping motors is comparable to closed-loop servocontrollers for many applications.

Conventional hybrid motors are rarely used in closed-loop systems because torque falls rapidly as current increases above the peak torque point — putting them outside typical control limits. Torque also decreases as speed rises. If driven too fast, hybrids lose positional accuracy by skipping steps.

Peak torque is limited by the flux level that saturates the rotor and stator teeth. But an enhanced stepping motor is now available that reduces saturation effects and produces 50 to 100% more torque than conventional stepping motors for the same input power.

Both conventional and enhanced stepping motors develop maximum torque when the rotor teeth are offset by one-quarter tooth pitch from opposing poles in the energized phase. The pole pairs develop appreciable torque even at zero current. Torque increases as current approaches the rated value.

At or near rated current in conventional stepping motors, a larger part of the air-gap flux traverses the gap from stator slot to rotor slot rather than from tooth to tooth, thus producing less torque.

The enhanced motor uses a relatively new stator design to get around this problem. Here, samarium-cobalt or neodymium-iron-boron magnets are embedded in slots between the teeth. More concentrated flux lines result between the rotor and stator teeth with fewer flux lines lost to the slotted air gap. These new slot magnets focus the air-gap flux, reduce leakage, and produce more torque.

Torque is also produced by a second pair of poles of the same phase placed 180° away from each other, and 90° away from the first pair. The second pole pair of the conventional stepping motor produces a torque that opposes the positive-acting pair. This negative torque is large at low currents but diminishes near rated current.

Enhanced motors also have large negative torques at low current. But positive-acting flux from the permanent magnets in the stator overcomes the small negative torque generated at rated current. The resulting torque then aids the pole pair producing the primary positive torque.

The slot magnets in enhanced motors provide peak torques reaching twice that of conventional stepping motors. Moreover, they can handle three times rated current compared to only two times for conventional stepping motors. Depending upon the inertial load, these new motors reach speeds of 5,000 to 10,000 steps/s. Corresponding torques are 200 oz-in. to 3,100 oz-in. in two to four-in.-diameter packages. Hybrid stepping motors also generally have high inertia (30 to 40,000 gm-cm^2), small step angles (0.5 to 15°) and high accuracy (±3%).

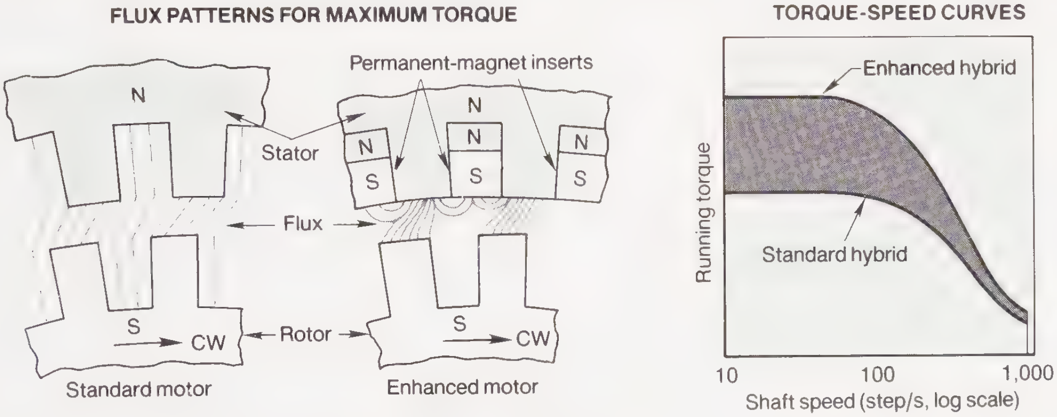
Microstepping

Step motors have several qualities that make them particularly suited for control systems. They are stiff when stopped, produce high torque for their physical size, and are brushless — making them virtually maintenance free.

Step motors have a serious drawback, however, when used for precise positioning. Standard hybrid step motors have a relatively large step size, usually 1⁄200 of a revolution or 1.8°. Such large step size can also cause motor-shaft oscillations at resonance points that occur at low speeds. But there is a widely used technique that retains the advantages of step motors and overcomes low speed roughness and low resolution. The technique is called microstepping.

Microstepping increases the position resolution and smoothness of conventional hybrid step motors. This is done with electronic control in the drive circuits. The drive subdivides each full step electronically into a large number of smaller steps. For example, a microstepping drive that subdivides each full step of a 200-step/rev motor into 125 microsteps produces 25,000 steps/rev (200 × 125 = 25,000).

Motors and drives must provide high



Slot magnets in the enhanced motors double the peak torque up to about 100 steps/s.

positional resolution in applications such as semiconductor fabrication. A 25,000 step/rev system attached to a 10-pitch leadscrew on an *X-Y* table can position a silicon wafer to one part in 250,000/in. This high positional resolution often eliminates gearboxes (and gear backlash) or other mechanical reducers otherwise needed to place wire bonds or test probes on exposed IC wafers. But many applications that do not need high resolution can also benefit from microstepping.

The biggest advantage of microstepping is smooth operation and the elimination of resonance over its entire speed range, typically 0 to 3,000 rpm. Smooth operation permits full torque utilization and freedom from rattling and mechanical wear.

The true accuracy of a microstepping system is usually less than its resolution. System accuracy is a complex function of motor accuracy, electronic tolerances, and errors in the mechanical transmission. But the combination of micropositioning and smooth operation has enabled microstepping systems to become standard in *X-Y* positioning systems requiring 1 μin. to 0.001 in. of resolution, and precision grinding, turning, and surface-finishing machines. Other precision motion-control applications include optical scanning and inspection, disk memory media manufacturing, and fiber-optics manufacturing.

Microstepping systems are generally easy to install and use because they have no tuning or setup requirements like typical servosystems. And they are stable and free from drift when stopped.

Microstepping drives have been available for at least 10 years in varying degrees of sophistication. Fully packaged motor-drive systems, card-level indexers and drives, and even chip sets aimed at high-volume original equipment manufacturers (OEMs) are now available in the U.S., Europe, and Japan.

Drives now provide resolutions from 2,000 (the minimum for microstepping) to 50,000 steps/rev. The largest drives can microstep 6.5-in. motors and can produce torques to 5,000 oz-in. Though many drive systems operate from an external dc power supply, there is an increasing trend towards direct, off-line systems that run at 120 or 240 Vac and have no internal transformer.

The elimination of transformers combined with today's high efficiency PWM amplifiers have made possible 0.5-ft^3 drives producing 2,000 W or more. Modern semiconductor power devices, including MOSFETs and IGBTs, help to increase package densities and often run cool enough to preclude fans.

Several indexers specifically for microstepping now have the ability to control multiple axes of motion. They can work from a variety of serial and parallel data buses including RS-232C, PC-AT, IEEE-488, Multibus, STDbus, VMEbus, and NUBUS. They are also relatively easy to program because of features in some stand-alone machines such as touch screens and simple menus.

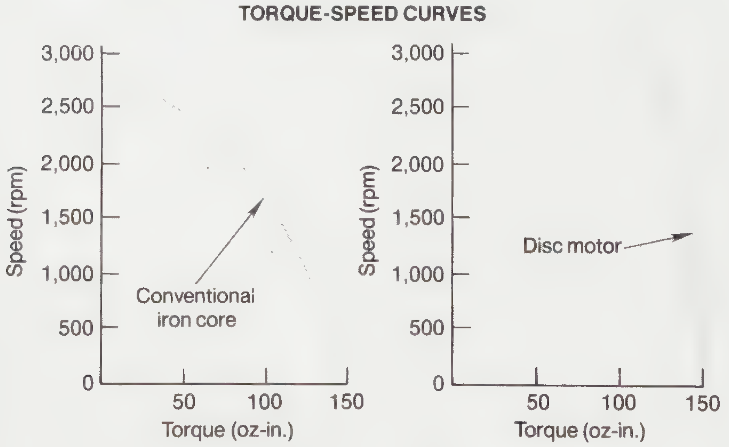
The most recent design trend is to integrate the indexer, drive, and power supply in one package. These systems are low in cost and sophisticated enough to control machines directly with no external computer or PLC. They store a variety of motion-control programs in nonvolatile memory. And some units accept position feedback from external optical encoders for critical positioning applications.

Rotary microstepping systems are by far the most widely used solution today, but direct linear microstepped motor-drive systems have also been developed. Most motion-control applications ultimately need linear motion and, therefore, require a leadscrew, belt, or band to convert shaft rotation into linear motion. The linear motor provides this motion directly and has virtually no backlash.

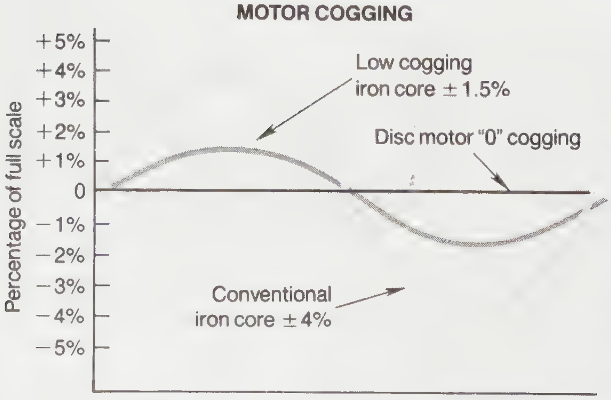
An advantage of linear motors is that they can provide speeds in excess of 80 in./s. Such speeds generally cannot be realized with leadscrew transmissions. High-speed linear motors are ideal for applications like printed-circuit-board component placement, insertion equipment, and inspection machinery.

Though microstepping provides increased positional resolution and smoothness, simple setup and freedom from drift is not appropriate for all motion-control applications. Simple microstepping systems operate open loop. There is no position feedback device to guarantee that the shaft position is correct. Normally this is not a problem for applications where shaft loads are relatively constant, such as *X-Y* tables, scanners, and packaging machines.

To head off problems with shaft po-



Disc motors maintain a nearly constant torque over their operating speed range.



Conventional iron-core motors have ± 4% cogging, low-cogging iron-core motors have ± 1.5%, but disc motors have virtually zero cogging.

sition uncertainties, an accepted design rule is to select a motor with twice as much torque as computed. Also, the stiffness of the shaft position is a function of the motor's rated torque and the load. The high efficiency of step motors in torque-per-volume and torque-per-ampere usually minimizes any problem with using a larger motor. In fact, a step motor that provides twice the calculated torque requirements may even be physically smaller than a similarly specified servomotor.

Large intermittent shaft loads in excess of the motor's available torque (which decreases with speed) can make the motor stall or lose position. Applications with widely varying torque demands, such as industrial robots, usually need a closed-loop system that can respond to these requirements efficiently. But closed-loop systems are more expensive. Feedback devices, such as encoders and resolvers, and a more sophisticated control system must be added. And these feedback elements tend to be more fragile than the motor itself.

The repeatability of a positioning system is often the most important design parameter. Open-loop microsteppers are very repeatable if the elements are selected as discussed.

Systems with large and variable frictions that load a large percentage of the motor's available torque can produce significant positional errors. As a guide, the shaft will deflect about 1° when a torque equal to half of the motor's rated torque is applied. This is not a problem for systems with repeatable loads, such as leadscrew-driven tables or scanners. But experts use a larger motor than torque calculations would normally indicate, simply to improve the overall system stiffness.

Disc motors

Disc motors are permanent-magnet stepping motors that exhibit performance comparable to that of hybrid motors. Rotors in disc motors are thin (typically less than 1-mm) discs, unlike the cylindrical rotors in hybrids and conventional permanent-magnet motors. Conventional permanent-magnet motors generally are limited to a minimum step angle of 30° for a maximum of 12 steps/rev.

Until recently, stepping motors provided 200 steps/rev at most, resolution previously available only through hybrid stepping motors. The latest version, which has a 0.9° step angle, provides 400 steps/rev. Due to very low distortion of the output torque sinusoid, microstepping accuracy is ±3% maximum.

The disc motors are generally a little over half as big as hybrid motors of equal power output and weigh 60% less. The rotors and magnetic circuits in the stators are quite light. And the stators are molded plastic rather than metal.

While a variety of disc motors have been available for about 20 years, they are still frequently used for their low in-

PM SERVOMOTORS

Fields in these motors are supplied by permanent magnets that create two or more poles in the armature by passing magnetic flux through it. The flux causes the current-carrying armature conductors to move, creating a torque. The flux remains constant at all motor speeds — the speed-torque and current-torque curves are linear.

Permanent-magnet motors provide several advantages and are available in fractional and low integral-horsepower sizes. Excitation power supplies and associated wiring are not needed. Reliability is improved since there are no exciting field coils to fail and there is no likelihood of overspeed due to loss of field. Efficiency and cooling are improved by elimination of power loss in an exciting field, and the torque-vs.-current characteristic is more nearly linear. Finally, a PM motor may be used where a totally enclosed motor is required for a continuous-excitation duty cycle.

Temperature effects depend on the kind of magnet material used. Ihp motors with Alnico magnets are affected less by temperature than those with ceramic magnets because flux is constant. Ceramic magnets ordinarily used in fhp motors have characteristics that vary as much with temperature as do the shunt fields of excited machines.

The absence of field control and special speed-torque characteristics are two disadvantages. Overloads may cause partial demagnetization that changes motor speed and torque characteristics until magnetization is fully restored. Generally, an ihp PM motor is larger and more expensive than an equivalent shunt-wound motor, but total system cost may be less.

PM motors have better starting torque, but approximately half the no-load speed of a series motor. In applications where compound motors are traditionally used, the PM motor could be considered where slightly higher efficiency and greater overload capacity are needed. In series-motor applications, cost consideration may influence the decision to switch. For example, in frame sizes under 5 in. in diameter, the series motor is more economical. But in sizes larger than 5 in., the series motor costs more. The larger sizes challenge the series motor with its high torques and low no-load speed.

Substituting rare-earth cobalt magnets for conventional Alnico and ceramic types cut motor weight by one-third and reduces motor diameter by 1 in. — without increasing cost or reducing torque capability. The high field strength of these magnets permits new designs such as "inside-out" configurations — with magnets on the rotor and windings on the stator — completely opposite from conventional motor design. The result is a smaller, lighter motor with less rotor inertia, greater heat dissipation and larger torque ratings.

Rare-earth cobalt magnets combine high coercivity (resistance to demagnetization) and good magnetic induction at a reasonable cost. Coercivity is very important in a motor — especially at heavy load. High coercivity produces a torque response that is linear with motor current. Getting this kind of linearity with conventional magnets requires expensive electronic controls or complex mechanical gearing.

Rare-earth magnets cannot be directly substituted for other types. Because of the extremely high-energy product of these magnets, one-for-one substitution for conventional magnets generally results in an overdesigned, uneconomical motor that is prone to malfunction. Using rare-earth cobalt magnets in a motor requires the same degree of planning afforded to other magnets.

Printed or disc motors contain large-diameter, short-length armatures of nonmagnetic material. Conductors are placed on the armature layers stamped from sheet copper, and the layers are welded together. The armature operates between permanent magnets. Thus, the magnetic flux generated by the magnets passes from one magnet across the armature to the opposite magnet and through a yoke to complete the circuit. Printed-circuit motors are used in systems requiring rapid response and operate at speeds from 100 to 4,000 rpm.

ertia and high torque. Recent improvements include neodymium magnets and power ratings up to 250 W for industrial-grade motors.

A conventional dc servomotor uses an iron-core armature with coils of wire wound in slots. However, some servomotors contain a flat armature constructed of several layers of copper conductors bonded to a rigid insulating disc. Since no iron is needed in the disc armature, it has a very low inertia. The thin armature design provides a high torque-to-inertia ratio. High ratios produce accelerations from 0 to 3,000 rpm in only 60° of rotation.

Conventional motors also produce cogging when the permanent magnets in the stator try to line up with the iron in the rotor. This happens even if the motor is not powered and may not be tolerable in some applications. In contrast, disc armatures contain no iron and, thus, do not cog. The result is a servomotor with very smooth rotation at any speed.

Stored energy in the inductance of an iron-core rotor produces arcing at the brushes during commutation. Arcing causes more brush wear than friction. But because a disc motor contains no rotor iron, it does not arc. As a result, brushes in a disc motor may last as long as the bearings.

The lack of inductance in disc rotors also gives a low electrical time constant. Typical time constants are less than 1 ms, allowing disc motors to reach full torque and acceleration much faster than conventional motors.

Most disc motors are rated for peak currents of ten times the continuous rating to overcome load inertias during acceleration and deceleration. Conventional motors are usually limited to peak currents of only two to three times continuous rating. Otherwise, higher currents produce a large magnetic field in the armature that can demagnetize the magnets.

Another type of flat servomotor for microstep positioning has a slightly different construction. Although it does not contain an iron-core armature, it does have a disc-magnet rotor. The motor stator has two phases that are driven with appropriate drives to achieve stepping. It has more rotor inertia than the previous disc motor, and less than constant torque over its speed range.

Disc motor makers are trying to improve their designs through development of an integral-velocity damper. The damper is a small motor attached to the servomotor shaft that is driven as a generator. It contains the same number of poles as the host servomotor (for example 1.8° steps and 50 pole pairs), but its output is amplified and fed back to the servomotor — out of phase. Such out-of-phase feedback reduces servo error. Primarily beneficial for incremental motion control, the feedback signal eliminates overshoot or ringing.

SERVOMOTOR SELECTION

NC machine controls use dc servomotors. When selecting an NC machine servodrive, the adequacy of the motor should be checked. In addition to being compatible with the machine and the controller, the motor must have certain characteristics for servodrive applications. Several key motor parameters hold the answers.

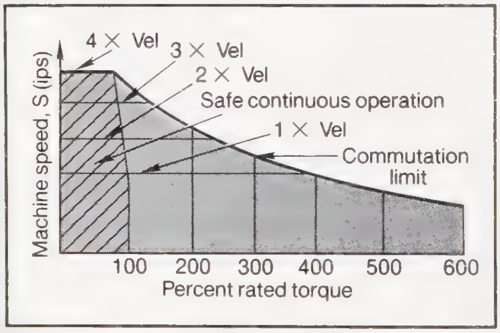
Torque-to-inertia ratio: A servomotor almost always contributes the most inertia to a machine-tool feed-motion system. Typically, inertia reflected back to the motor shaft is less than 30% of motor inertia in a high-performance machine tool. Therefore, a motor's torque-to-inertia ratio can determine feed-motion capability for fast acceleration. The higher the ratio, the more torque available for acceleration.

Motor bandwidth measures the motor's ability to respond to small, rapid changes in the input voltage. The bandwidth W in radians/s is expressed as:

$$W = \sqrt{\frac{K_v K_t}{JL}}$$

where K_v = cemf/speed, V/rad/s; K_t = torque/armature current, lb-ft/A; J = total inertia, lb-ft-s^2; and L = armature circuit inductance, H.

Generally, motor bandwidth should be three times greater than the gain of the digital controller. For example, if used with a controller gain of 1 ipm/0.001 in., the motor bandwidth should be greater than $3 \times 16.67 = 50$. All servomotors have a bandwidth of 100 or more, which corresponds to a controller gain of 2 ipm/0.001 in. Because gains higher than 2 ipm/0.001 in. are seldom used, motor bandwidth is seldom a limiting factor.



Commutation limit: Servomotors have a constant field-strength/flux-density ratio, therefore, armature current is directly proportional to torque. Repeated high-torque demands on the motor (for high machine-element acceleration) speed up brush wear. Excessively high torque demand at high motor speeds could cause flashover between adjacent commutator bars, resulting in etched and burned areas on the bar edges and, in permanent-magnet motors, demagnetization. Thus, machine acceleration requirements should be translated into terms of motor torque to find out if the motor will exceed its commutation limit while meeting acceleration demand.

This procedure is done with the aid of the servomotor commutation-limit curve which gives the speed-torque envelope within which the motor can safely produce the demanded torque.

Drive motor candidates

Type	Max power (hp)	Typical top speed (rpm)	Torque/inertia ratio (lb-ft/lb-ft^2)	Max bandwidth (rad/sec)
Moving coil (shell)	0.5-1	4,500-5,500	200-250	1,500
Printed circuit	7	3,000-4,000	[illegible]	1,000
Permanent magnet*	10-15	850-3,000	15-30	100

*Higher hp ratings are available with different performance characteristics.

Dc servomotors

Dc servomotors are normally used as prime movers in computers, numerically controlled machinery, or other applications where starts and stops are made quickly and accurately. Servomotors have lightweight, low-inertia armatures that respond quickly to excitation-voltage changes. In addition, very low armature inductance in these motors results in a low electrical time constant (typically 0.05 to 1.5 ms) that further sharpens motor response to command signals. Servomotors include permanent-magnetic, printed-circuit, and moving-coil (or shell) motors. The rotor of a shell motor consists of a cylindrical shell of copper or aluminum wire coils which rotate in a magnetic field in the annular space between magnetic pole pieces and a stationary iron core. The field is provided by cast Alnico magnets whose magnetic axis is radial. The motor may have two, four, or six poles.

Characteristics include inertia, physical shape, costs, shaft resonance, shaft configuration, speed, and weight. Although these motors have similar torque ratings, their physical and electrical constants vary.

Selection: The first selection approach is to choose a motor large enough for a machine that has already been designed; the second is to select the best available motor with a specific feature and then build the system around it; and the third is to study motor performance and system requirements and mate the two.

The final servosystem design is usually the least sophisticated that meets the performance specifications reliably. Requirements may include control of acceleration, velocity, and position to very close tolerances. This says that the servo designer must define the system carefully, establish performance specifications, determine critical areas, and set up tolerances. Only then will the designer be able to propose an adequate servosystem and choose a motor type. ■

HYDRAULIC CARTRIDGE VALVE TECHNOLOGY
Item 2171

The latest and most complete handbook of hydraulic cartridge valve technology. Over 500 technical charts, illustrations, and photographs. Key technical terms are explained the first time they are used for easy reading. Lists of DO's and DONT's help guide the reader. This book is a useful guide to every hydraulic engineer, designer, builder maintenance technician, distributor, educator and reference library. Contents Include: *Communications, Basic Operating Characteristics, The Spool or Poppet Choice, Screw-in Type Cartridges, Insert-Type Valve Cartridges, Slip-in-Type Cartridges with Cap, Cartridge Valves at Work in Mobile Hydraulic Systems, Cartridge Valves at Work in the Manufacturing Sector, and Troubleshooting Machines with Cartridge Valve Circuits.*

By John J. Pippenger, P.E.; 338 Pages. . .Hardbound **$85.00**

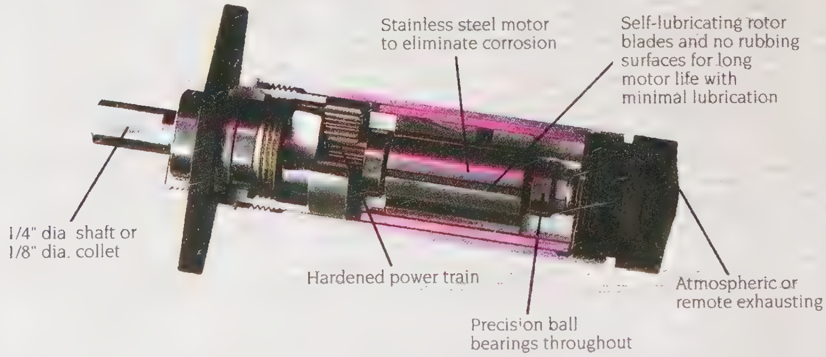
Order Toll Free 800-321-7003 (In Ohio 216/696-7000)

Or send your order to:

Penton Education Division
1100 Superior Avenue
Cleveland, Ohio 44114

Conserve energy.

Unless you are using the smallest, most efficient Air Motor to meet your speed and torque requirements, your excess air consumption is costing you money.


Stainless steel motor to eliminate corrosion
Self-lubricating rotor blades and no rubbing surfaces for long motor life with minimal lubrication
1/4" dia. shaft or 1/8" dia. collet
Hardened power train
Atmospheric or remote exhausting
Precision ball bearings throughout

Micro Motors offers you Air Motors that are small in size but big on performance and quality. At only 3/4 of an inch in diameter, these miniature precision motors consume only 4.8 CFM of air at 90 psi, while producing stall torques from 3.5 in-ozs to 9 ft-lbs, at free speeds of 50,000 RPM to 1 RPM. Over the past 20 years, our design engineers have adapted this small, reliable power source into a variety of products in the industrial, dental, and medical fields. Let them help you select from our standard models or design this motor into your product. Autoclavable designs are also available.
Call (800) 562-6204.

Micro Motors, Inc.
151 E. Columbine Ave., Santa Ana, CA 92707 USA (714) 546-4891 FAX (714) 546-1109

Circle 380

Electrical drives

Controller manufacturers are improving features such as motor protection and brushless dc commutation.

One operation of all motors, whether powered by ac or dc, calls for a controller. The simplest of controllers, called starters, merely connect and disconnect a motor to a power source. But controllers also protect the motor from overload and prevent excessive branch-circuit current. In some cases they protect the equipment they power and the personnel that operates it. More sophisticated controllers, sometimes called drives, regulate motor torque, speed, or horsepower in response to remote commands.

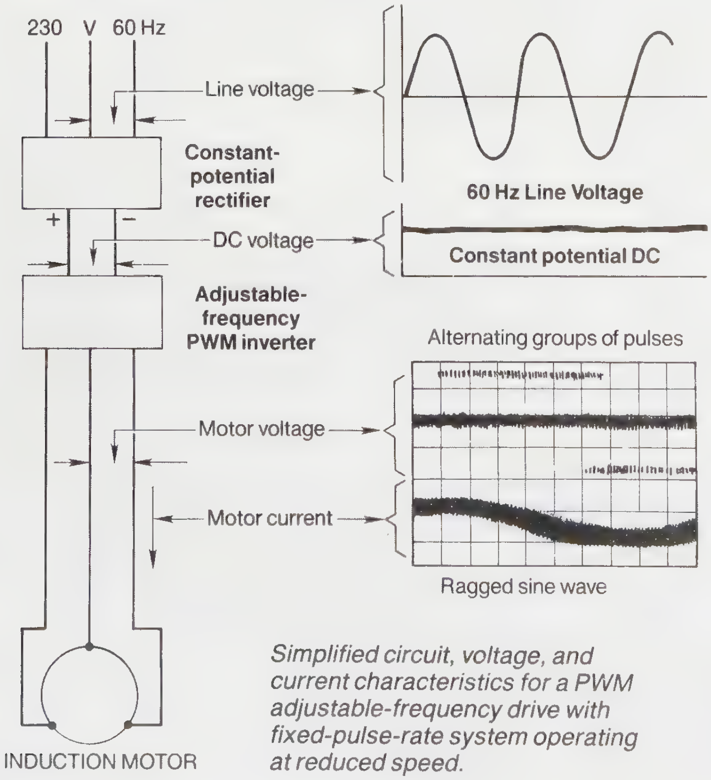
Ac controllers

Adjustable-speed ac drives offer advantages over dc drives because of the simplicity, high-speed capability, and low-maintenance requirements of squirrel-cage motors. Squirrel-cage motors can also adapt to adverse conditions such as dirty air, explosive atmospheres, and inaccessible locations.

USING PWM

A pulse-width-modulation (PWM) system rectifies 60-Hz line voltage to produce constant potential dc voltage. The dc voltage is broken by the PWM inverter into alternating groups of short pulses in a pattern that, when applied to an ac induction motor, produces a ragged sine-wave current. One such PWM system produces pulses at a fixed rate.

In that system the voltage and the wave shape are determined by variations in the pulse length as each cycle progresses. A second system produces a fixed number of pulses/cycle, in which case the voltage is determined by the length of each pulse. The wave is shaped by variation of the time between pulses during each half cycle. The frequency, in both cases, is determined by the rate of polarity reversals.



Simplified circuit, voltage, and current characteristics for a PWM adjustable-frequency drive with fixed-pulse-rate system operating at reduced speed.

Ac motor drives: The ac induction motor is sometimes considered a constant-speed motor, and it is, in fact, when connected to a 60-Hz power source. However, its speed can be adjusted if power is supplied by an adjustable-frequency drive. Speed is also adjustable by means of eddy-current drives.

The primary elements of an adjustable-frequency drive are a rectifier and an inverter, which convert 60-Hz power to adjustable-frequency ac. Two ways to provide this conversion are the six-step method and PWM method.

Two conversion methods are hard to compare because there are many variations. However, the attributes include:

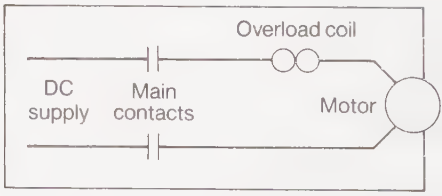
Six-step method:

- Can operate at higher frequencies.
- Produces less motor noise.
- Produces less stress on motor insulation.

PWM method:

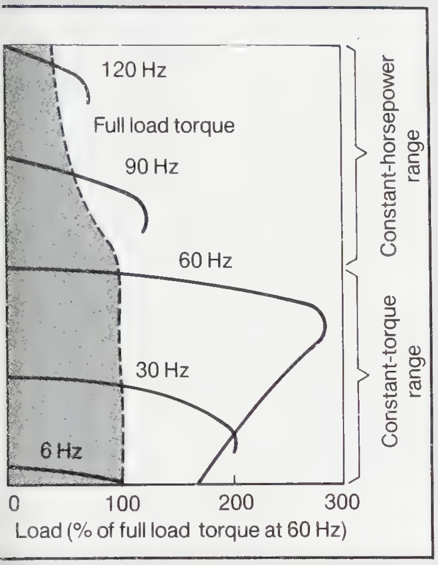
- Produces less motor losses in some versions.
- Provides low-speed torque without cogging.
- Can provide stall torque.

Eddy-current drives: The primary elements of an eddy-current drive are an ac motor, an eddy-current clutch, a tachometer, and a solid-state regulator. The eddy-current clutch consists of a drum driven at constant speed by the ac motor and, concentric with the drum, a rotor for driving a load.



Torque is transmitted from the drum to the rotor through an adjustable magnetic field that is established in an air gap between the two members. The magnetic field is produced by a coil on the rotor. Power for the coil, which is equivalent to about 2% of the drive rating, is provided by the regulator. The regulator adjusts coil excitation to a level where output speed, as indicated by a tachometer, is equal to that set on a speed-reference potentiometer.

DJUSTABLE-REQUENCY DRIVE PEED-TORQUE HARACTERISTICS



ypical speed-torque characteristics for induction motor operating at arious frequencies (with voltage oost at lower frequencies).

Eddy-current drives typically have 30-to-1 speed range at constant torque, produce intermittent torque up to 200% of rated, provide 0.5% speed regulation from no load to full load, and when stalled, deliver up to full-load torque without pulsations.

Dc controllers

Dc motors are energized or started by manually operated switches or magnetically operated contactors. Manually operated switches handle a modest range of motor currents. Magnetically operated contactors usually provide a safer and more convenient means for controlling motor power circuits, particularly in large horsepower ratings.

The inrush currents of line-started dc motors are limited only by the "at-rest" resistance of the circuit and may be ten times the full-load current. Because dc motors have commutators that can be damaged by excessive starting currents, full-voltage starting is not always possible, except for small motors that have relatively high winding resistance. Compound-wound motors up to 7 hp and other dc motors up to 2 hp can usually be line started.

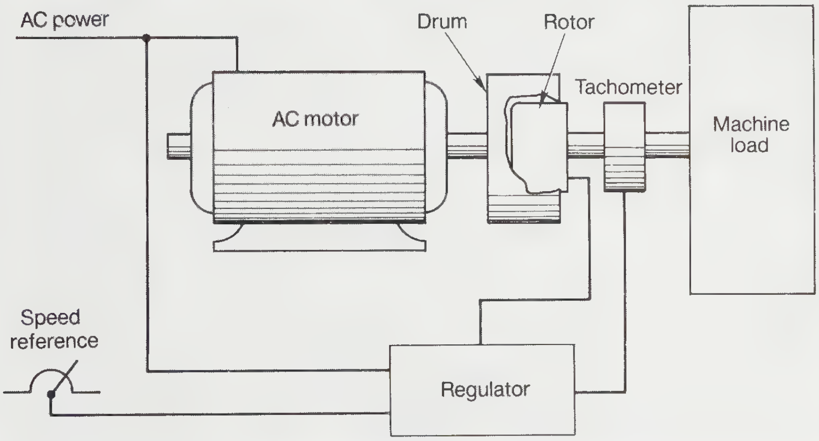
A dc motor can commutate more current at low speeds than at high speeds. With the armature practically standing still, most commutators handle currents as high as six times the full-load rating of the motor without excessive sparking.

A starting or current-limiting resistor must be added for larger motors. Resistance is gradually shorted out as the motor accelerates. The motor counter-emf increases with speed, thus reducing the current. When the motor reaches its base or normal operating speed, all starting resistance is shorted out, and the motor draws its normal running current.

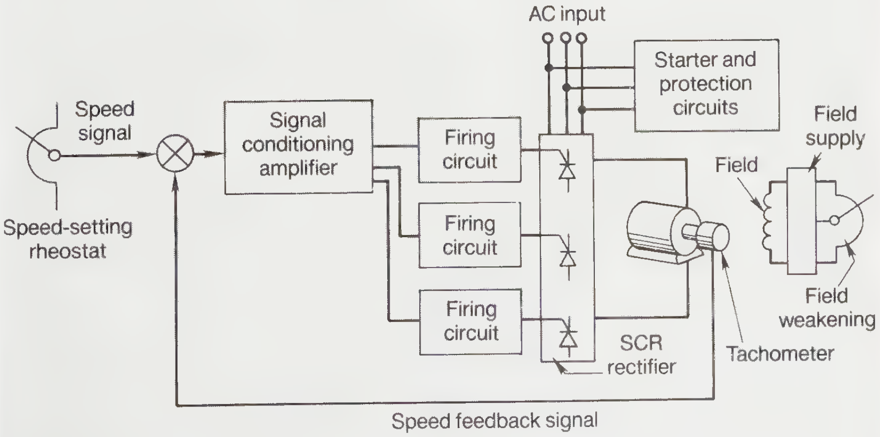
If magnetic starters are used for acceleration, starting resistance can be shorted out in one or more steps, depending on motor size and the smoothness of acceleration desired. There are three methods for obtaining automatic acceleration: time-limit, current-limit, and speed acceleration.

Dc motor drives: Direct-current motors are used for adjustable-speed drives because of their inherent ease of speed adjustment. The speed of a dc motor is a function of the armature and field voltages. Control and adjustment of armature voltages result in a constant-torque drive, while constant horsepower is obtained by field-voltage control.

EDDY-CURRENT DRIVE



ADJUSTABLE-VOLTAGE DRIVE



In a typical adjustable-speed dc drive, the signal from the speed-setting rheostat is combined with the speed-feedback signal. The combined signal is fed to signal-conditioning circuitry that regulates the firing circuits for each thyristor. The firing circuits produce a string of timed pulses that control when the thyristors are turned on and, thus, the output of the rectifier.

SECO® CD-Compact Digital AC drives . . .

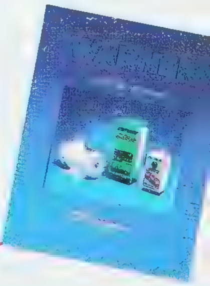
New!
CD Range Expanded
Now covers motors
through 40 H.P.

The Standard for the future is here Today!

There is little doubt of the direction that industrial motor control is taking. In the very near future, serial link communication via RS-485 will be the basic requirement for the remote management of the industrial process. The new CD drives from SECO offers tomorrows requirements . . . today! Fully digital, with 29 programmable parameters accessed, set and maintained in real time, as well as all diagnostic and status conditions.

- Ultra compact. Microprocessor based, state-of-the-art surface mount technology.
- 1-5 HP, 230 VAC or 1-~~15~~ 40 HP, 460 VAC
- Local or remote programming capability
- Full, 5 year warranty
- Available now, at more than 500 Warner Electric distributor locations.

Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog P-986
815/389-3771
Fax 815/389-2582

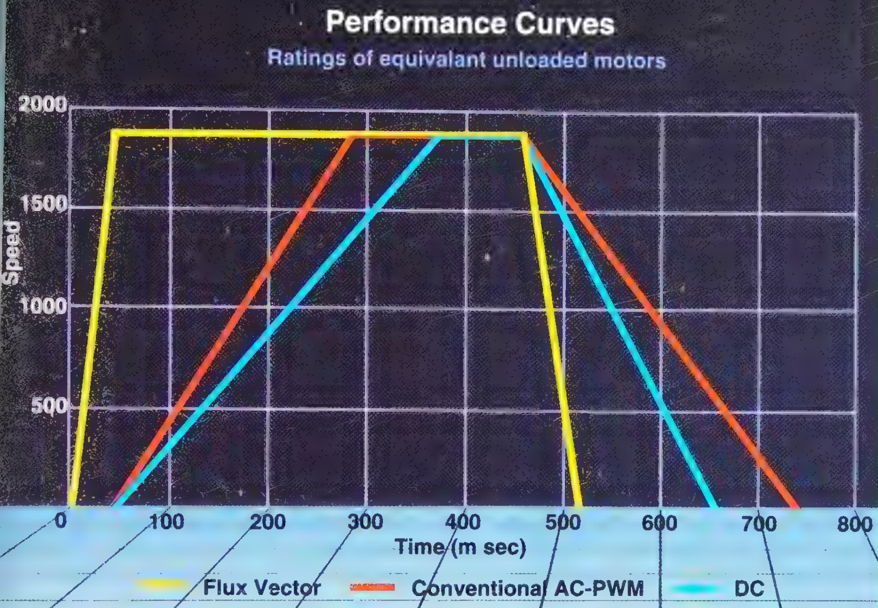


WARNER ELECTRIC

DANA

Circle 381

Finally, an AC Inverter that provides DC performance



SECO
VR
DANGER! RISK OF ELECTRIC SHOCK!
DISCONNECT SUPPLY AND WAIT 5 MINUTES BEFORE REMOVING ANY COVERS

SECO® VR Series
Flux Vector AC Motor Drives

Until now the only means to achieve full speed and torque control over the entire motor speed range required a DC or Servo driven motor.

SECO's Flux Vector technology changes this. Utilizing an AC Induction Motor with a shaft driven encoder the SECO series VR Flux Vector A.C. Inverter provides high performance speed and torque control. All this for a price comparable to 3 phase D.C. packaged drives.

- 1-40 HP
- Drives AC Induction Motor
- 0.1% Speed Control
- Simple Set-up
- Surface Mount Circuitry
- Fully Digital w/RS485 Serial Communication
- Full Torque 0 to 6000 rpm
- Electronic Line Shaft Lock
- Spindle Orientation
- 5 year warranty

Write or call Warner Electric
South Beloit, IL 61080
815/389-3771
Call 800/234-3369
Fax 815/389-6377
Ask for Catalog P-1004

WARNER
CONTROL TECHNIQUES

Circle 382

SECO® ...Quadraline 7000

high performance, responsive, reliable, regenerative DC motor speed control

Feature Packed

1. Smooth control
- Precise consistent positioning
- Full wave, four quadrant operation provides accurate, smooth bidirectional motoring with simultaneous braking torque

2. Rapid, continuous cycling
- Electronic reversing eliminates mechanical contractors for rapid, reliable, repetitive reversal of motor rotation

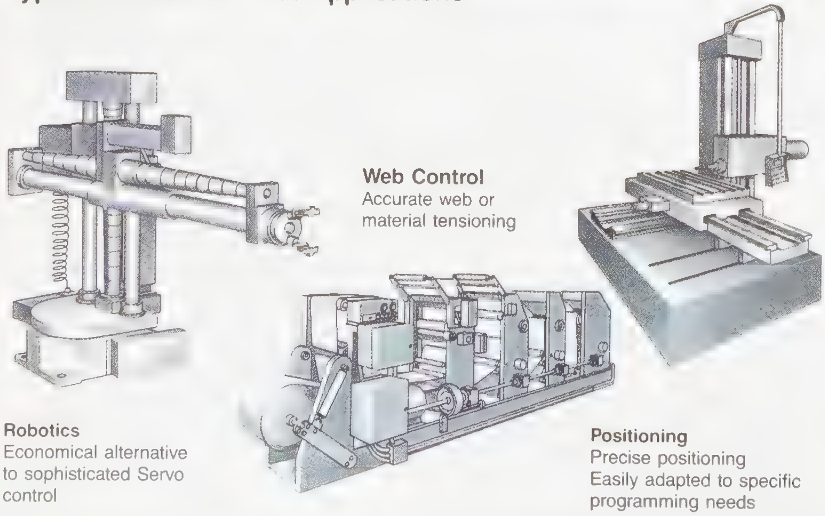
3. Continuous braking torque with no power loss
- Regenerative operation causes motor to act as generator to provide braking torque

4. Wide range of models and adjustments
- 1/4 HP to 5 HP • chassis mount
- optional enclosure • fully protected
- single phase • 115/230 VAC input

5. Local service and stock availability
Our customers are served promptly through a nationwide network of 850 distributor outlets.

UL Listed

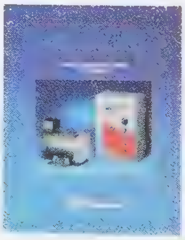
Typical Quadraline 7000 applications



Robotics
Economical alternative to sophisticated Servo control

Web Control
Accurate web or material tensioning

Positioning
Precise positioning
Easily adapted to specific programming needs



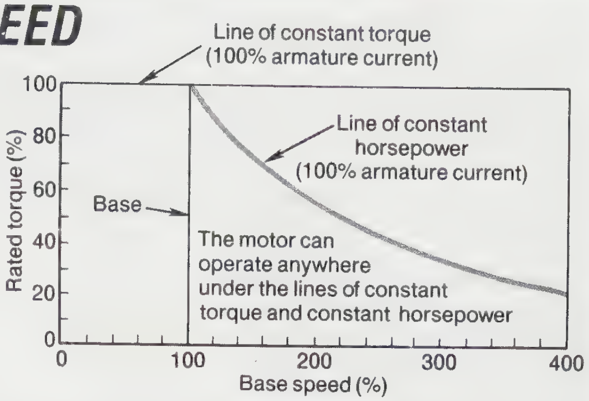
Warner Electric
South Beloit, IL 61080
Call 800/234-3369
Ask for catalog P-821-7
815/389-3771 • Fax 815/389-2582

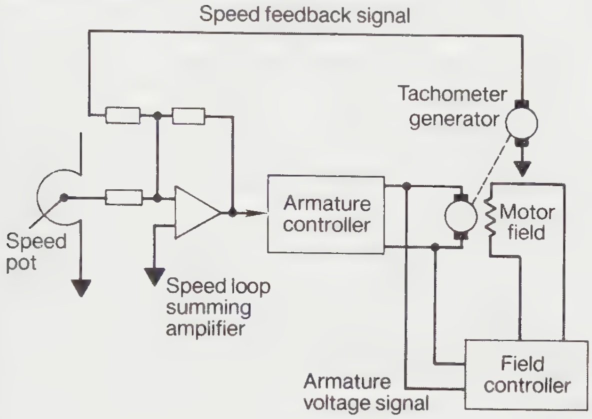
WARNER ELECTRIC
DANA

Circle 383

USING FIELDS TO CONTROL SPEED

A dc motor can operate below base speed by reducing armature voltage, but to operate above base speed, the motor field must be weakened by reducing field current. Since output torque is directly proportional to field strength, weakening the field to increase speed reduces output torque. But, because the power output is proportional to the product of speed and torque, the output horsepower remains constant above base speed. Field-weakening methods range from adding a ballast resistor in series with the wound field to automatic systems that regulate both armature voltage and field strength with a single control.

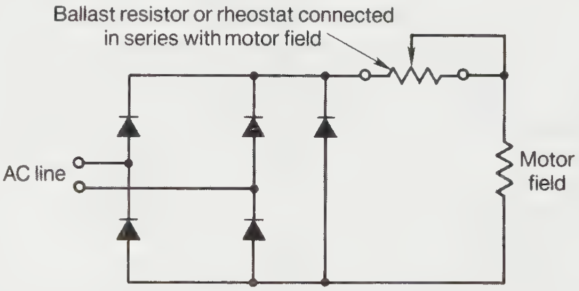




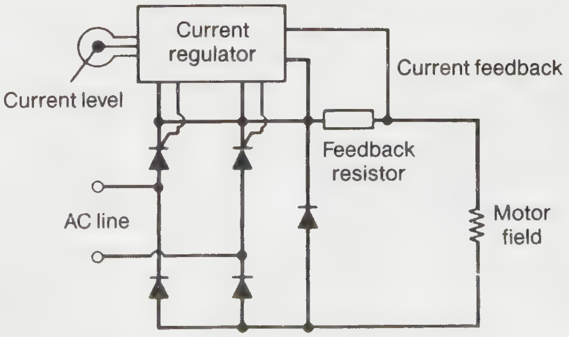
Automatic-field weakening: This method allows the motor to operate throughout the entire constant-torque and constant-horsepower ranges with only one speed control. The field-current regulator is controlled by armature voltage. When armature voltage is between zero and 85% of rated voltage, field current is maximum. As armature voltage increases from 85 to 100%, field current is automatically reduced to provide maximum motor speed. Small speed changes can be made quickly because field strength is varied as a function of armature voltage. (Normally speed change by field control is relatively slow because of the large electrical time constant of the field.) The penalty for this fast response is a 15% loss of the maximum continuous horsepower capability near 100% base speed. This loss occurs because field strength begins to diminish at 85% armature voltage.

Ballistic and rheostat control: Ballasting is used when required motor speed does not match standard motor base-speed ratings. For example, standard dc motors are available with base speeds of 2,500 and 3,500 rpm. If an operating speed between these two values is required, a ballast resistor could be added in series with the field of the 2,500-rpm motor. The resultant reduced field strength enables the motor to operate at a speed higher than the base-speed rating with maximum rated armature voltage applied. However, adding the resistor brings the iron core of the motor out of saturation and the motor can no longer stabilize itself. And motor warm-up and ac-line variations can cause drastic changes in maximum speed.

Rheostat control is used in applications where field current must be adjustable. This control is subject to the same effects of warm-up and ac-line variations. Additionally, improper operation of the rheostat can cause motor damage. If the rheostat is suddenly turned from maximum to zero resistance, full field current is applied to the motor. This causes motor counter-emf to increase, and the motor or controller (or both) could be damaged. Overvoltage-protection circuits must be added if the rheostat control range causes more than a 20% change in motor speed.


Ballast resistor or rheostat connected
in series with motor field
AC line
Motor
field

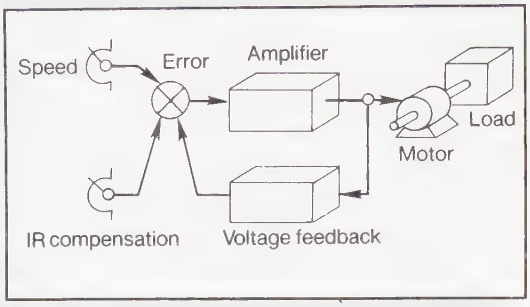
Electronic-field trim: Field trim, or ballasting, is provided electronically by using a phase-controlled SCR power supply to regulate field current. In this method, a portion of field current is fed back to a regulator circuit that compensates for ac line-voltage variations and field-resistance changes caused by motor warm-up. A potentiometer can provide a reference-input signal so that the SCR power supply performs like a rheostat. In this case, overvoltage protection is provided by monitoring armature voltage to control the rate of field-current increase.



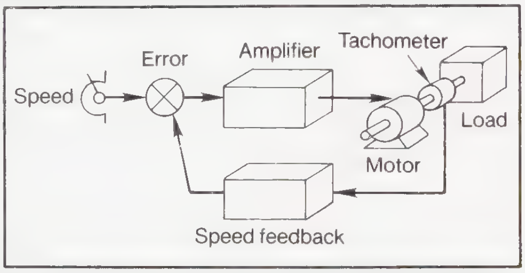
CONTROLLING SPEED WITH VOLTAGE

Internal losses including windage, friction, and *IR* drop, can cause an unregulated dc motor (driven at rated armature voltage), to lose up to 4 to 5% of its operating speed from no-load to full-load conditions. Feedback-control techniques can improve motor speed regulation.

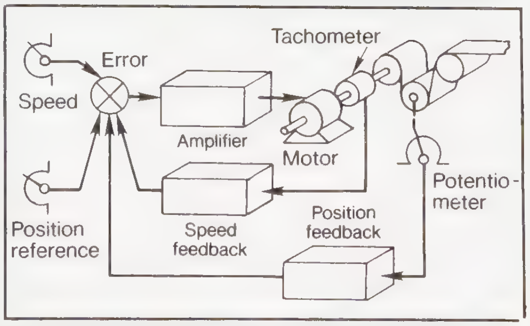
Voltage control: In this common system, a voltage signal is obtained directly from the output terminals of the drive and compared to the reference signal from the speed-setting potentiometer. An *IR* compensation circuit is normally used to improve speed regulation and linearity of the potentiometer.



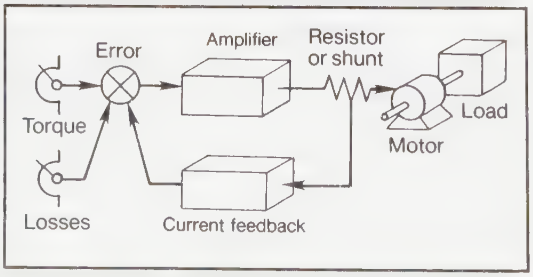
Speed control: Velocity feedback is used when an absolute value of motor-shaft speed is required. Shaft speed is measured by a tachometer whose signal is compared to the speed-reference signal. In this system, the inertias of the motor and load combine to present a mechanical time constant to the system. And if inertia is large, special compensating circuits may be required. For higher accuracy, a digital tachometer may be used with a digital/analog converter to provide the feedback signal.



Position and tension control: Position control is required when adjacent sections of a process machine must operate at the same speed. The feedback device is normally a potentiometer connected to a position-sensing roll. Linear or rotary reactors or a photoelectric sensor can be used. Tension-control systems are used where direct tension measurement is required. The feedback device is a force transducer mounted on each end of a tension-sensing roll. In both of these systems, a speed feedback loop may be required to prevent hunting and oscillation.



Torque control: When motor torque needs to be controlled independent of motor speed, constant current must be supplied to the motor. In this system, motor-armature current is measured with a wire-wound resistor or meter shunt in the output of the drive. The signal is compared to the current reference signal. Torque available to the load is generated torque minus all friction and windage losses. These losses are offset by biasing the control circuitry.



Dc drives consist of a controlled-voltage power supply, one or more dc motors, and a feedback system which controls dc voltage as a function of speed.

Adjustable-voltage dc drives are equally applicable to single or multiple-motor applications. The power-conversion unit can be sized to supply a single motor or several motors as long as the speed of all motors can be adjusted according to a common signal. Motors do not have to operate at the same speed, however, since adjustable resistors can vary the motor field voltage.

Controlled-voltage supplies are divided into converters and semiconverters.

Semiconverters have diode rectifiers in one side of the bridge and thyristors in the other side. A commutating diode is placed across the output. Semiconverter circuits provide unidirectional current and voltage, and cannot be used for reversing or regeneration (where power is fed back into the circuit by the motor). The motor can be reversed by contactors, and automatic dynamic braking (power generated by the motor is fed to a resistor grid) can be furnished for slowdown and stopping.

CONTROLLING ACCELERATION

Time-limit acceleration brings the motor up to speed in a definite time regardless of load. Various timers are used to initiate operation of the accelerating contactor.

Current-limit acceleration is used for heavy inertia loads. In the system, a current-sensitive relay initiates closing of the accelerating contactor when the motor current reduces to a suitable value, such as 125%. The starting load must be consistent and not much more than full load because motor current must reduce to the value set on the current-sensitive relay to short out the resistance.

Speed acceleration uses the motor counter-emf signal when the starting resistor should be shorted out. A voltage-sensitive relay is used to measure voltage. If the motor fails to accelerate to the necessary speed, the resistor will not drop out; unless rated for continuous service, the resistor will burn up.

Converters have thyristors in all legs of the bridge, and can be used for reversing and regeneration applications. These units impose less ripple current on the motor than semiconverters.

Dynamic braking

Motors should not coast more than a few shaft rotations after being deenergized. Critical applications use electromechanical clutch and brake devices to stop loads when motor power is removed. However, when motor braking can be less precise, dynamic braking may be a less-costly solution.

Dc motors are normally braked by disconnecting the armature from the power source. The armature is then short circuited or a current-limiting resistor placed across the armature terminals while the field coils remain energized. In either case, armature current reverses, armature torque reverses, and the motor tries to reverse. The speed in the forward direction rapidly decreases as does the voltage generated in the armature. At the point of reversal or zero speed, generated voltage is zero. The motor stops at this point since current cannot flow and no more reversing torque is generated.

The value of the shunting resistor controls the braking rate. A small resistance allows a large current flow. Since braking torque is proportional to armature current, the motor and load stop in a short time. Some resistance is recommended to limit the severity of braking, especially with gearmotors.

Induction-type motors are generally braked by removing ac power and applying dc. The motor then acts like a dc generator with a short-circuited armature. The electrical output of the generator has high circulating currents in the shorted (squirrel-cage) rotor bars, and rotational energy is dissipated in the form of rotor heat. The motor is quickly brought to a stop.

Dc braking sources vary from batteries and highly filtered power supplies to full-wave and half-wave sources or a charged capacitor. The choice is based on cost and degree of braking required. Generally, pure dc is better than less-continuous dc, but more expensive.

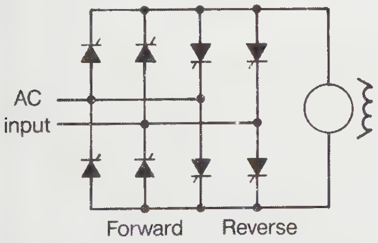
Selecting electrical drives

The days of matching catalog motors

DC DRIVE CONVERTERS

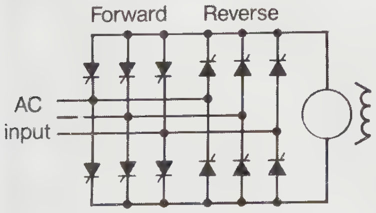
SINGLE-PHASE DUAL CONVERTERS

Dual converters control voltage and current (and, thus, speed and torque) in both directions of motor rotation. The gating and control circuitry provides smooth transition from forward to reverse speeds and prevents circulating current between the converters. For large drives with light torque requirements in the reverse direction, it is common to provide half capacity in the reverse thyristors.



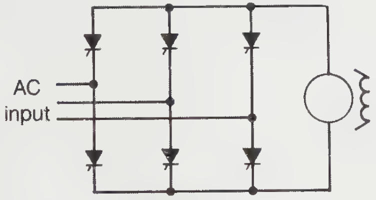
THREE-PHASE DUAL CONVERTERS

These are similar to single-phase dual converters and have additional diodes and thyristors to handle the three-phase input. Applications include mill and process-line drives from 20 to 7,500 hp.



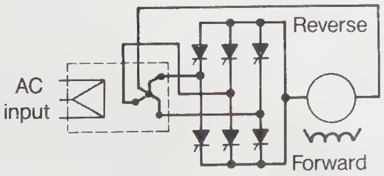
THREE-PHASE SINGLE CONVERTERS

These drives are inherently nonreversing and nonregenerative, but by reversing the motor field with contactors, a reversing-regenerative drive is possible. Control for such a drive is much more complicated than a control for dual converter, so applications are limited. The usual range of single converters is from 20 to 7,500 hp.



THREE-PHASE SINGLE-WAY CONVERTERS

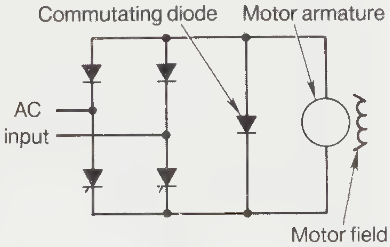
Single-way dual converters provide voltage and current in either direction, and need only six main circuit thyristors for a full-reversing, regenerative drive system. A transformer is required to connect one end of the motor armature to neutral. Applications include spindle drives and small mill and process-line drives from 5 to 100 hp.



SINGLE-PHASE SEMI CONVERTERS

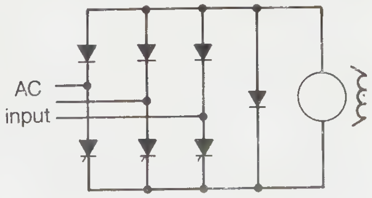
The thyristors are pulsed alternately with the changing polarity of the input current. Output current is regulated by delaying the trigger pulse. The commutating or freewheeling diode bypasses inductive motor current that would keep the thyristor on.

Single-phase semiconverters are normally used for fractional to 5-hp motors. They are usually packaged drives, and are available with options such as dynamic braking, jogging, threading, acceleration/deceleration, and speed regulation. Reversing is provided by contactors.



THREE-PHASE SEMI CONVERTERS

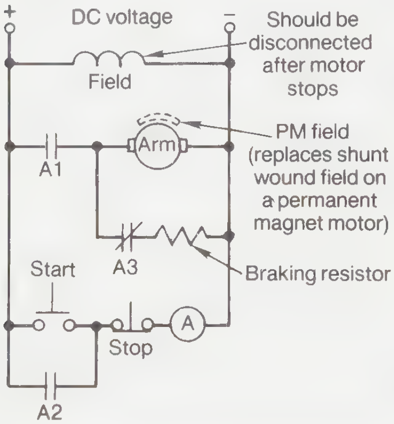
These have a diode and thyristor to handle the three-phase input. Three-phase semiconverters normally have a range of 5 to 200 hp.

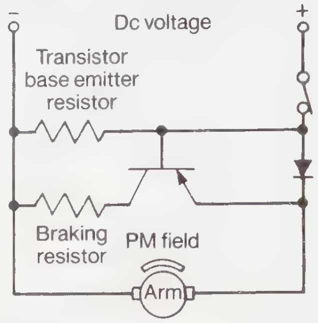


BRAKING BRUSH-TYPE MOTORS DYNAMICALLY

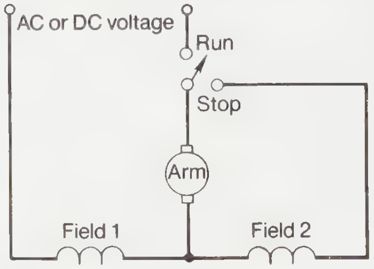
Dynamic braking of dc motors occurs when the armature terminals are disconnected from the power supply and then connected together, while the field is energized. The resultant armature current from the counter-emf voltage creates a magnetic field that opposes motor rotation.

Shunt wound or permanent magnet: When the motor is running, normally open relay contacts A1 and A2 are closed, and normally closed contact A3 is open. When the STOP button is pressed, A1 opens to disconnect one side of the armature from the power source. Holding-contact A2 opens, and braking contact A3 closes to put the current-limiting resistor in series with the armature circuit.


+
DC voltage
−
Field
Should be disconnected after motor stops
A1
Arm
PM field (replaces shunt wound field on a permanent magnet motor)
A3
Braking resistor
Start
Stop
A
A2



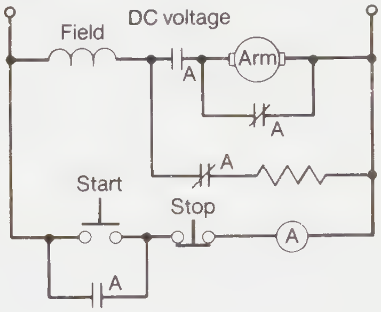
Permanent magnet: With the switch in the RUN position, the diode biases the transistor off. With the switch in the STOP position, the transistor conducts during braking because of the armature CEMF polarity.

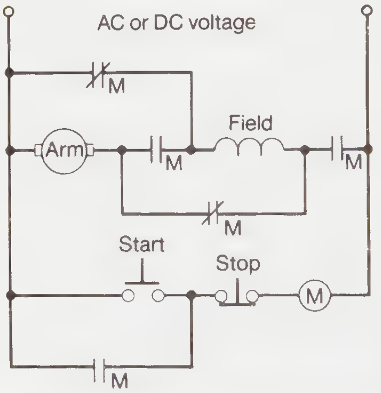


Three-lead series: The motor is braked by connecting the armature across the opposite set of field coils through simple switching.

Four-lead series: This is similar to the shunt-wound motor. The only difference is a current-limiting resistor in series with the field winding during braking.

Another way to brake this motor is to remove it from the power source and connect it to the armature across the field with relay-contact switching.





BRAKING GEARMOTORS

It is important to analyze the dynamic braking of inertial loads driven by gearmotors, because of its unique considerations. Otherwise, damaged geartrains can result.

Determining load inertia: If the gearmotor output shaft is not directly coupled to the driven load, and there are additional speed-changing elements between the output shaft and the load, then the equivalent inertia at the gearhead drive shaft must be calculated by using

$$WK^2_{lds} = (WK^2_l)\left(\frac{N_l}{N_{ds}}\right)^2$$

where WK^2_{lds} = load inertia seen by the drive shaft at drive-shaft speed, lb-in.^{2}; WK^2_l = load inertia at driven speed, lb-in.^{2}; N_{ds} = drive-shaft speed, rpm; and N_l = speed of the load, rpm.

The inertia WK^2 for simple solid discs used as flywheels is half the weight in pounds times the square of the radius in inches. Handbooks provide equations for calculating inertia of other shapes.

Determining brake torque: If the external load inertia WK^2_{lds} is significantly less than the internal component ($WK^2_r \times R^2$), then it is possible to brake the load by dynamically braking the motor. However, if external inertia is greater than internal, then external braking or clutching should be used. The following equation is useful:

$$T_{ds} = \frac{[(WK^2_r \times R^2) + WK^2_{lds}](N_{ds})^2}{221{,}185(\Delta_{ds})}$$

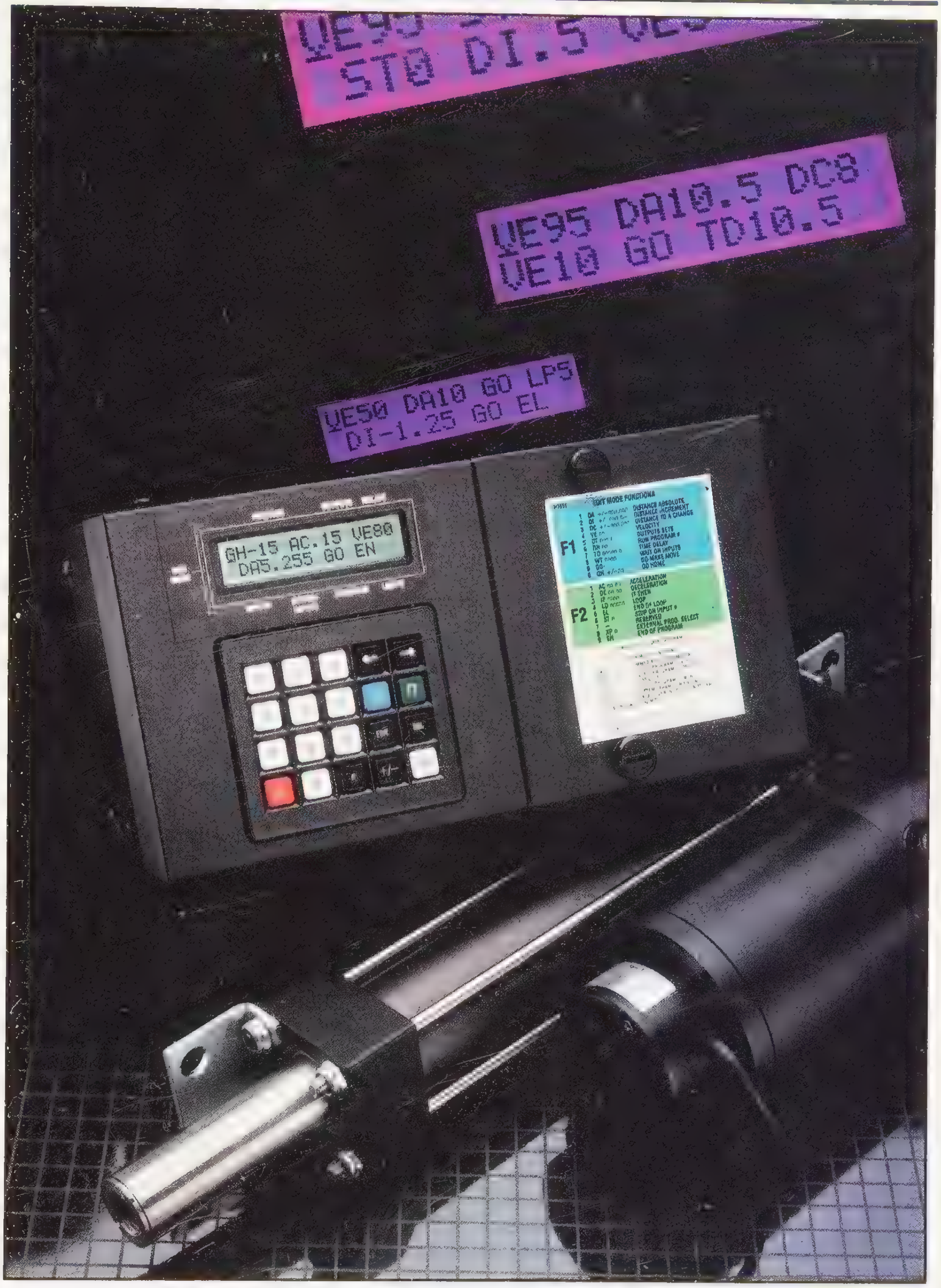
where T_{ds} = torque required to bring the gearmotor drive shaft to rest during braking, lb-in.; WK^2_r = internal inertia contributed by the motor's rotating member (rotor or armature), lb-in.^{2}; R = ratio of the gearmotor gearhead; Δ_{ds} = number of desired drive-shaft revolutions during the braking period; 221,185 = a constant associated with inch-system units. If SI units are used (Newtons & meters instead of pounds of force and inches), the constant becomes 5,615. When $R = 1$, this equation applies to nongeared motors.

This equation approximates the external braking torque required to bring the system to rest within a given time after the electrical power is disconnected from the motor, but braking is not yet applied. If analysis proves dynamic braking to be feasible, use minimum braking power to get the required results.

1.
Mount

2.
Wire

3.
Run



The Industrial Devices Approach to Linear Positioning…

echnological developments by dustrial Devices Corporation have ought electrically-powered linear tuators into the mainstream of high-rformance, heavy-duty industrial plications. Founded in 1975, dustrial Devices pioneered the use of ectric actuators for industrial plications by developing highly accurate systems to meet the demands of robotics, semiconductor, automotive, process control, and other speed and precision-oriented markets. Today, Industrial Devices is the recognized leader in electric cylinder technology. With Industrial Devices' introduction of high-performance DC motor and step motor-powered systems, electric cylinders now provide fine position control, repeatability and programmability—even under strenuous loads and 100 percent duty cycles. Where uniform acceleration, variable velocity, or multiple mid-stroke stopping points are desired, IDC electric cylinders are the best linear motion solution.

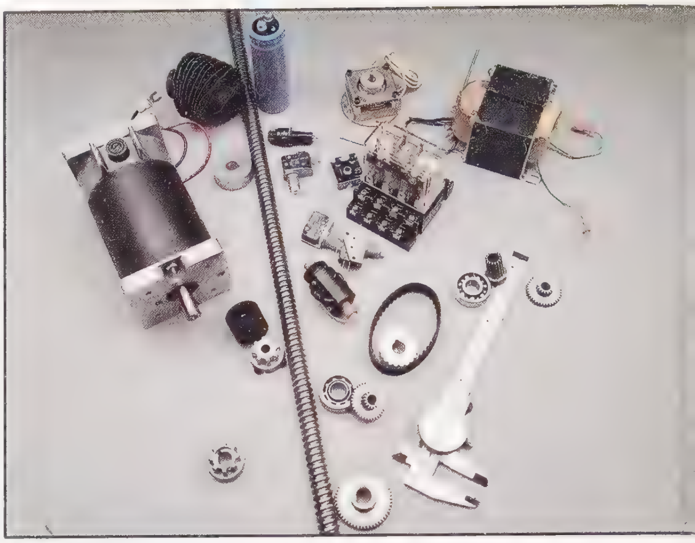
Circle 384

Engineered So You Don't Have T

Considering the "do-it-yourself" approach?

There are times when engineering an application in house, at first glance, seems the most cost-efficient, "smart" route to a solution. After all, having ownership of each and every step in the process will result in a well-planned, efficiently produced application right?

When you take into consideration the time spent away from other projects, the technical limits of one engineer versus the collective and specialized expertise of many, and the costs both planned and unexpected, the do-it-yourself approach can be overwhelming. To determine the best approach, in terms of cost for value, consider the following steps in the design process.



Steps In Designing A Cylinder

1. Calculate column load requirements
2. Calculate critical speed limits for the leadscrew
3. Select and specify leadscrew type
4. Design bearing mounts
5. Design and manufacture attachment of drive nut to load
6. Calculate motor torque
7. Determine position sensing techniques and fabricate mountings
8. Design a power transmission system that tailors motor characteristics to lead screw
9. Fabricate mountings and ensure proper alignment
10. Determine if covers or shields are required
11. Procure components
12. Assemble and test completed system

An estimated break-down of time required for a cylinder includes:

Concept and design	32 hours
Procurement	8 hours
Assembly and test	6 hours

Based on an average 'engineer's labor cost' of $50 per hour, this simple application would take 46 hours and cost $2,300 in time alone.

In addition, the control aspects of the system must be considered. This could be as simple as purchasing a DC power supply and switches for $100, or as sophisticated as a control configuration for: multi-position and repeatable stopping; controlling speed uniformly and smoothly across a wide range; or setting up encoder feedback. Once in place, testing and fine-tuning add hours to the task.

Consider This...

Industrial Devices Pre-Packaged Systems Solutions

A pre-packaged Industrial Devices system solution is littl more than a phone call away. Simply contact us with application requirements—load, speed, stroke, duty cycle and linear positioning accuracy— and we'll recommend th best system for your application.

The IDC pre-packaged system solution to your application is:

- *Pre-engineered*
- *Pre-tested—as a system*
- *Delivered in two to three weeks*
- *Covered by a one-year warranty*
- *Ready to mount, wire and run!*

Industrial Devices is committed to the development and application of new ideas and technology to solve linear motion problems with conveniently packaged, easy-to-us systems.

If your application requires special design consideration, our inventory of specialized assemblies and controls may provide the solution you're looking for. Call us at 415/883-3535.

Circle 384

The Electric Cylinder Difference

rinciple of Operation

dustrial Devices electric linders differ from other ectric linear actuators in at they are specifically ngineered to provide the gh-performance, high duty ycle and long life expected f rugged industrial motion ontrol products.

peration of Industrial evices electric cylinders is imple and involves a inimum of moving parts.

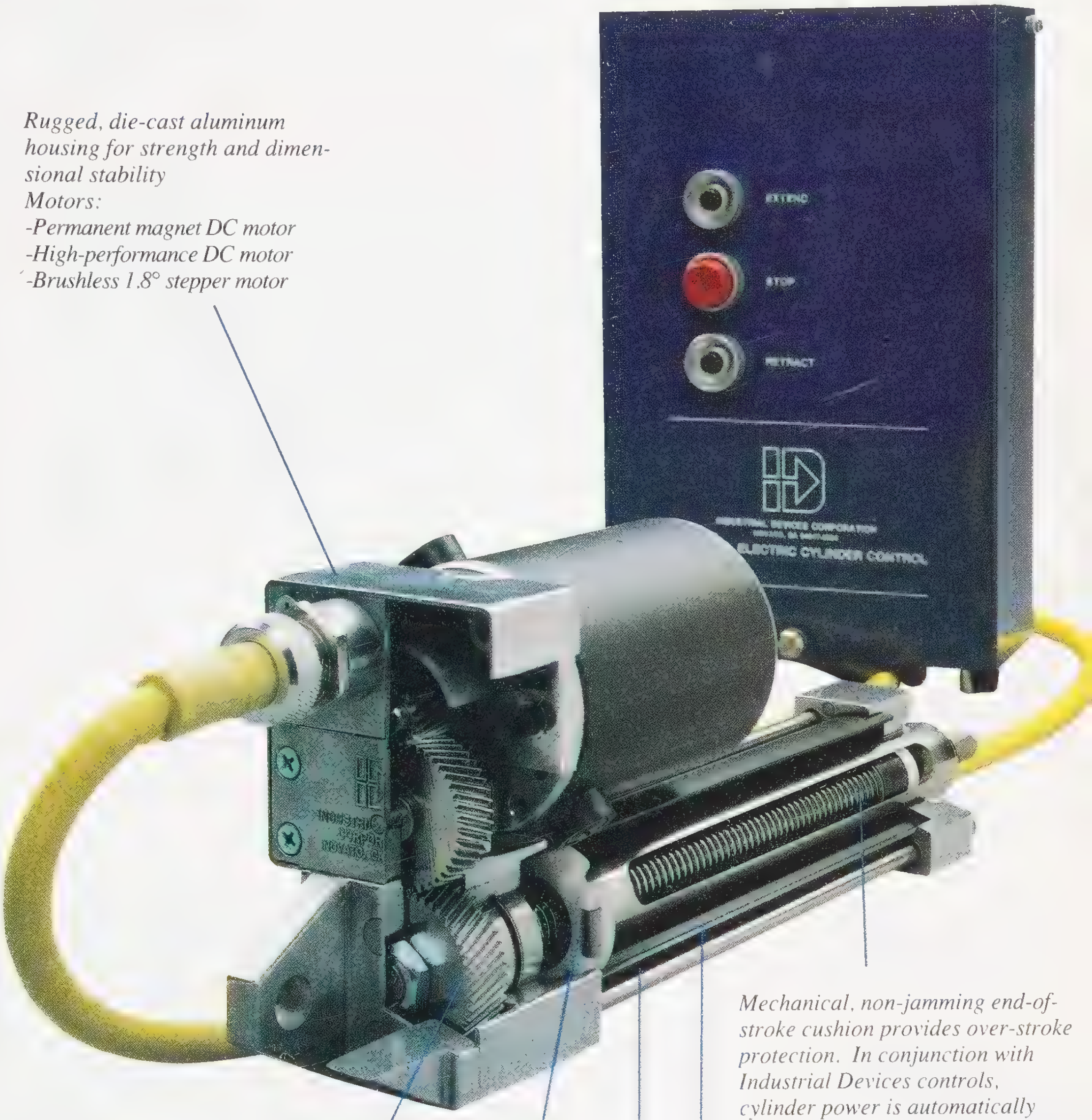
Vhen power is applied, the otor—through the timing elt drive, gear drive, or oupling—rotates the lead crew, causing the drive nut o translate, extending or etracting the thrust tube.

Our unique guide system revents rotation of the drive ut, and eliminates any orque loading of the nachine linkage.

An elastomeric spring cushions the impact at the ends of the stroke when compressed by the drive nut on extension and by the output rod end on retraction.

The Teflon wiper seal keeps contaminants out and assures smooth, quiet operation.

Reversing polarity to the motor reverses the direction of operation. IDC electronic controls provide precise starting, stopping and velocity control of the motor o achieve maximum performance.



Rugged, die-cast aluminum housing for strength and dimensional stability
Motors:
-Permanent magnet DC motor
-High-performance DC motor
-Brushless 1.8° stepper motor

Mechanical, non-jamming end-of-stroke cushion provides over-stroke protection. In conjunction with Industrial Devices controls, cylinder power is automatically shut off

Timing belt and geared drives provide long life for a wide variety of drive ratios

Extruded aluminum guide cylinder is hard-coat anodized and Teflon impregnated for long life, permanent lubrication, resistance to corrosion, and protection of all internal components from contamination

Lubricated polyacetal drive nut provides low-friction, smooth operation, and high resistance to shock loads

Acme or recirculating ball bearing lead screws provide smooth, high-thrust drive; acme screws hold load without power

Circle 384

Electric Cylinders for Today's Automated Industries...

Industrial Devices electric cylinders are engineered to meet a growing need for linear motion solutions throughout automated industry. This is exemplified by the wide range of industries and applications requirements served:

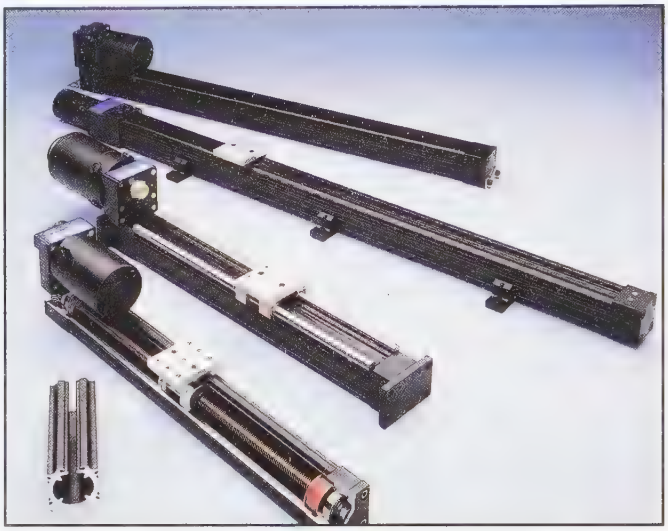
X-Y Stages
Automatic Tool Changers
Precision Grinders
Workpiece/Part Orientation
Parts Clamping
Pick and Place Systems
Precision Valve Control
Material Cutting
High-Speed Product Sorting
Conveyor Diverters and Gates
Bottle Fillers
Wire Winding
Welding
Chip and Wafer Handling
Die Cutters
Open/Close Doors
Ventilation Control Systems

New! Engineering Guide

The 136 page catalog provides performance data, product comparisons, selection considerations and dimensions. To receive your copy contact one of our more than 100 sales and engineering representatives, or contact our applications engineering department at (415) 883-3535.

Electric Linear Actuators & Controls

Compact Rodless Cylinders Provide High Speed and Extended Travel



- Speeds to 150 inches per second
- Standard travel lengths to 72 inches
- Capable of supporting 250 pound loads
- Position resolution to 0.0005 inch
- 800 pounds of thrust
- 100 percent duty cycle rated
- Position repeatability to ±0.0005 inch
- Select from three motor and control types
  - Low cost DC
  - High performance DC
  - Step and microstep

Standard Cylinders and Controls

- 800 pounds of thrust
- Speeds to 30 inches per second
- Standard travel lengths to 18 inches
- Position resolution to 0.0005 inch
- 100 percent duty cycle rated
- Position repeatability to ± 0.0005 inch
- Select from three motor and control types
  - Low cost DC
  - High performance DC
  - Step and microstep

Industrial Devices Corporation

64 Digital Drive • Novato, CA 94949 • 415/883-3535 • FAX 415/883-2094

Circle 384

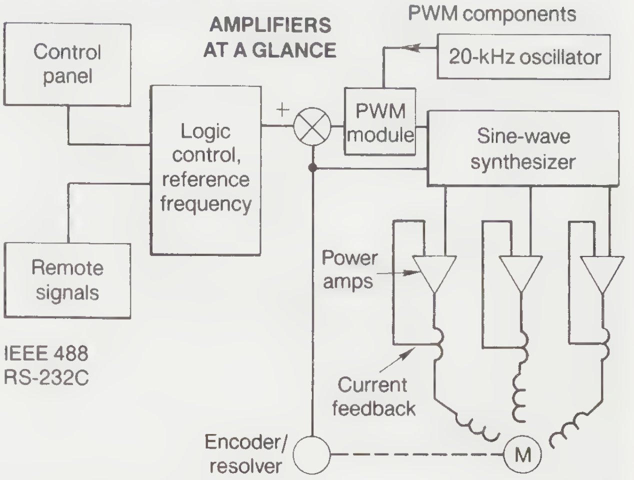
UNDERSTANDING CONTROLLERS AND AMPLIFIERS

A motor controller performs three main functions. It first routes current to the motor windings according to rotor position. It also transforms the input supply voltage into a controllable voltage and current supply to the motor for speed and torque control. Finally, it handles all speed and torque feedback loops to meet prescribed static and dynamic qualities.

Commutation is one controller duty. In brushless motors, commutation takes place by sensing rotor position. Based on rotor position, the controller routes current into the appropriate stator windings to generate motor torque, thus following rotor movement.

Amplifiers that provide power for such systems are either linear or pulse-width-modulated (PWM) units. PWM amplifiers (also called switchers) employ transistors that are turned on and off like a switch. Because the output stage rapidly switches from a nonconducting to fully conducting state, dissipation in the output stage is minimized. Forced-air cooling is seldom needed. A benefit of this approach is that it provides more power in a small volume. A disadvantage is that the switching transistors can disturb adjacent sensitive circuits.

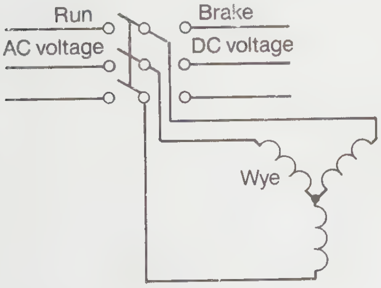
Linear amplifiers are preferred from a control standpoint in that they have no significant control lag within the operating bandwidth. They are easily compensated and are capable of providing speed control over a wide range. They are least troublesome in terms of generating EMI and, thus, are often used in systems that must operate near low-level signal apparatus such as magnetic recording systems. The only real disadvantage to linear systems is that they sometimes need forced-air cooling because of their high-dissipation output transistors.



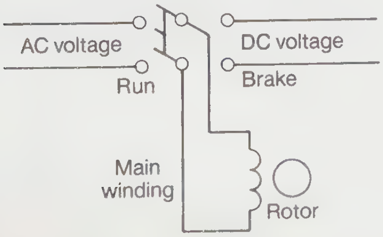
DYNAMIC BRAKING FOR INDUCTION MOTORS

Ac motors are generally braked by removing ac power and applying dc. The motor then acts like an ac generator with a short-circuited armature.

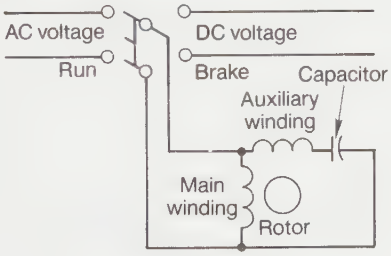
Polyphase: Polyphase motors, delta, or wye-connected, are dynamically braked by disconnecting the motor from the ac line and connecting two windings in series with a dc supply. A 3pdt switch is required.



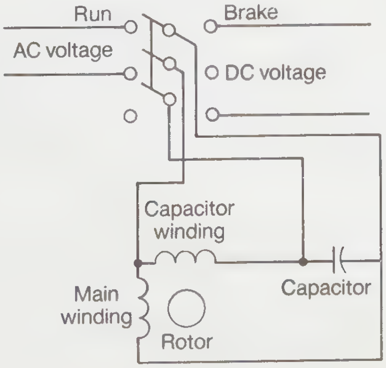
Shaded pole: This motor is dynamically braked by applying dc in place of the ac with a dpdt switch.



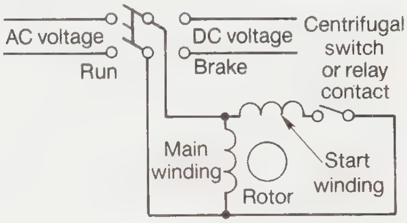
Permanent-split capacitor: This circuit arrangement uses only the main winding for braking.



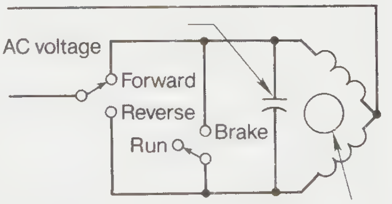
With the 3pdt switch in the BRAKE position, the two windings are connected in series with the dc power supply to stop the motor.



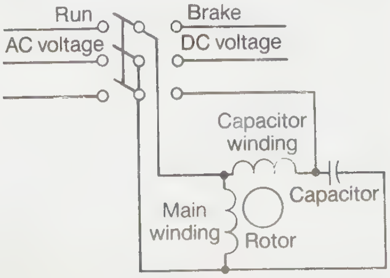
Split phase: The dpdt switch transfers the main winding from ac to dc for braking.



A simple spdt switch shorts the capacitor in the BRAKE position. This is limited to reversible, subfractional horsepower, permanent-split capacitor, high-slip nonsynchronous, and hysteresis-synchronous motors.



To use the auxiliary winding for braking, use a 3pdt switch. The third pole connects the windings in parallel.



with available power supplies and controllers may be over. The old way of handling motion control was to choose off-the-shelf devices with ratings usually exceeding actual application requirements. This was especially true for controllers available in three or four models each designed to accommodate a range of motor sizes. The result was often an overrated (in current, voltage, or both) and expensive controller driving a larger-than-needed motor.

Overspecified systems of this nature may be all right in small quantities. But in volume OEM production where price is an important consideration, a better matching between components becomes critical.

In addition, the performance demands made on today's motion-control systems frequently eliminate off-the-shelf products from contention. These demands concern high acceleration and deceleration rates, tight speed accuracies, and fine adjustment increments that are difficult to reach using collections of standard products.

Another approach is increasingly being used to meet such requirements. Rather than make do with standard parts, it is often better to design the motor and controller together as an optimized system. This technique involves constructing a motor from a few building block components and matching it with a power supply and controller that together provide the needed performance at a minimum cost.

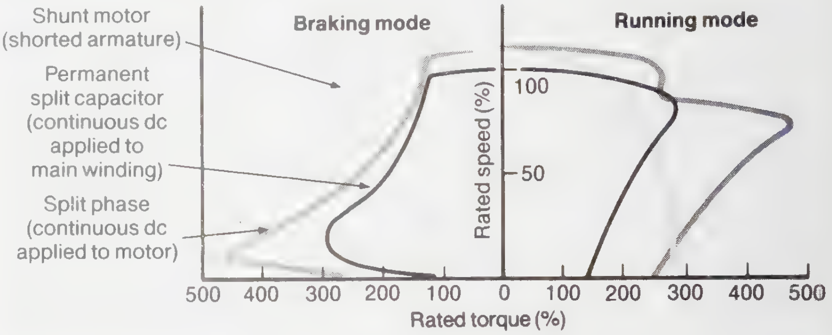
Successful examples of this approach can be found in the retrofitting of electronic controls to mechanical production or manufacturing equipment in machine tools; filament-winding, packaging and labeling machinery; avionics controls and actuators; industrial sewing machines; and optical recording equipment.

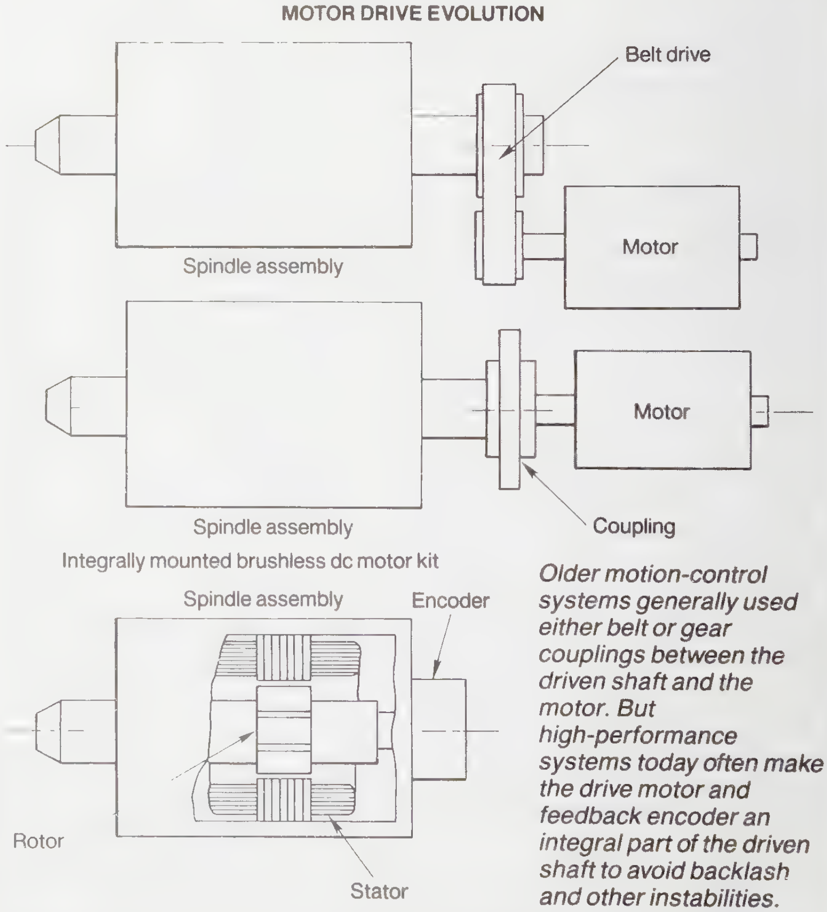
A number of problems can make standard motion-control products suboptimum. One is that off-the-shelf motors generally come with a set performance and fixed dimensions. Shaft diameters and lengths, motor diameters, and supply voltage requirements are generally invariable.

It is often difficult to get motor manufacturers to make even slight changes in these specifications. For example, ordering a standard motor with a special rear shaft extension may result in a sharp jump in both price and lead time, assuming the vendor is willing to make the modification at all.

DYNAMIC-BRAKING CURVES

Motors respond differently to dynamic braking. Although motors are not selected primarily for braking, users should know how the motor reacts to dynamic braking. This information is contained in the second quadrant of the speed-torque curve. Essentially, the flatter the bottom part of the curve, the more positive the stopping action. Average braking torque produced by the motor is the area within the curve in the second quadrant divided by the speed at the instant of braking.





Older motion-control systems generally used either belt or gear couplings between the driven shaft and the motor. But high-performance systems today often make the drive motor and feedback encoder an integral part of the driven shaft to avoid backlash and other instabilities.

Some motor suppliers address the need for such special products through field modification centers located at a distributor site. These centers may offer some limited variations, usually only for brush-type motors. It is also interesting to note that the modifications these centers make do not address the overall system or the controllers.

In many cases, other factors can complicate the design process, even

New Polyspede inverter delivers 150% torque as low as 1 Hz — quietly

Parameters can be monitored, programmed or changed through a personal computer or programmable controller (by others). A keypad programmer is standard. Capacities 1 through 30 hp.

Now you can start, inch, cycle or sequence high-breakaway loads — even at low speed settings — with a standard squirrel cage motor. In the Polyspede VXT inverter, advanced ROM software gives vector-like performance with *no encoder on the motor shaft.*

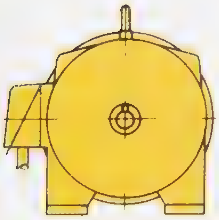
Notice the curves below. The VXT allows the motor to deliver 150% rated torque from 1 to 60 Hz. On the other hand, with the conventional inverter the available torque is only about 37% at 1 Hz; it only reaches 150% at 60 Hz.

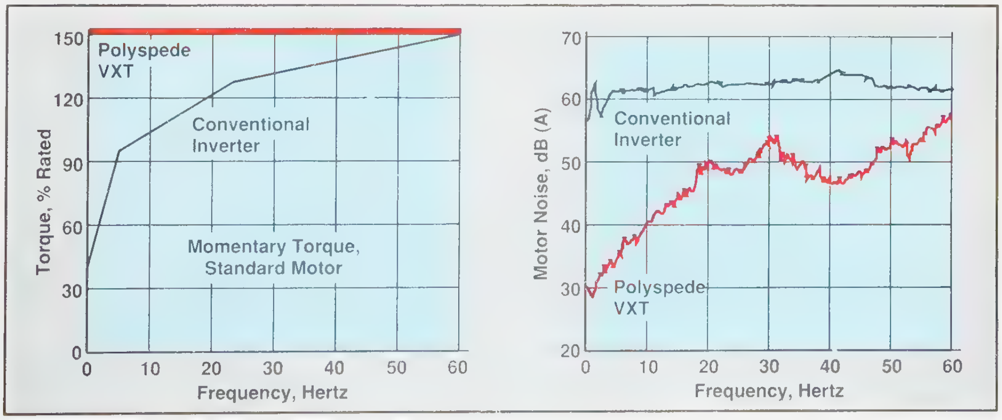
Smooth running inverter = quiet motor

At the same time, the motor noise level with the VXT is only 37 dB at 5 Hz, versus 60 dB with other inverters. This is because the VXT inverter, with its 16 kHz switching frequency, closely emulates a pure sine wave, resulting in quiet operation over the entire speed range.

There are still more advantages, such as dynamic braking; programmable sequencing (as many as 10 steps); a keypad programmer; plus communication with a computer or programmable controller.

Call us for detailed specifications and application data.





Note: Polyspede Model VXT can produce output frequencies up to 375 Hertz.

POLYSPEDE

Polyspede Electronics Corporation • 6770 Twin Hills Avenue • Dallas, Texas 75231
Telephone 214-363-7245 • FAX 214-363-6361

Circle 385

when an off-the-shelf motor seems to provide the right performance. For example, space limitations may eliminate standard motors from consideration. Numerous applications today call for a motor built on and around the driven shaft, particularly when the system must be torsionally stiff (no belts), or have zero lost motion (no gears), or where shaft runout requirements are in millionths of an inch.

These systems are often typified by a need for high-speed accuracy (±0.001%) and are generally regulated with phase-locked servosystems where an optical tachometer feedback signal is compared to a reference frequency. The comparison generates a system error proportional to both shaft velocity and position. Typical 0-dB bandwidth is on the order of 100 to 300 rad/s. To obtain acceptable system stability in such uses, it is necessary to minimize effects such as spring rate, or at least to place the response outside the system bandwidth.

The alternative approach of designing motors and controllers together as a system is made practical by modern motors that are basically constructed of a few common components. This allows manufacturers to make motors in a kit form that can be assembled around the drive spindle during manufacture.

The process of custom tuning all motor parameters for a given application is not as difficult as it may sound. While this philosophy suggests a generation of specials without end, there is actually considerable fallout of common parts and subassemblies when the motor, controller, and feedback devices are considered as a system.

One reason is that the brushless motors often used in high-performance motion-control applications have quite a simple construction. Motor components can be thought of as building blocks consisting of laminations and magnets. This allows motion-control suppliers to inventory a large array of basic building blocks used in developing motors for special requirements. All other components such as copper wire, bearings, motor housing parts, shaft and rotors, shaft encoders and readers are either generally available commodities or can be modified with short lead times.

In terms of controller performance, optimization generally considers factors such as the actual peak and rms torque requirements or whether a dc supply voltage is available. The need for an enclosed or open frame and special interface specifications can also be built into custom specifications.

For example, consider simple velocity control over a 500 to 5,000-rpm speed range. Many standard controllers require either a resolver or encoder to provide the feedback signal for velocity. But such feedback components might be an overspecification for this speed range. Instead, Hall-effect commutation sensors on the motor itself might provide velocity sensing that would work as well.

The motor-controller interface often can be optimized in other ways. One way is to design the BEMF constant of the motor and the dc bus voltage of the controller to yield a maximum speed that is less than 10 to 15% above the highest operating speed. This ensures that certain failure modes do not produce high runaway speeds.

Other optimization is possible in direct-drive applications where speeds are low (0 to 500 rpm) and torques high. Here, custom motor/controller combinations can be configured to get more power from smaller motors, use less energy for a given task, obtain faster acceleration and deceleration rates to improve throughput, reach higher or more precise operating speeds, meet precise positioning criteria, improve heat dissipation for cooling, and reduce maintenance or lengthen operating life.

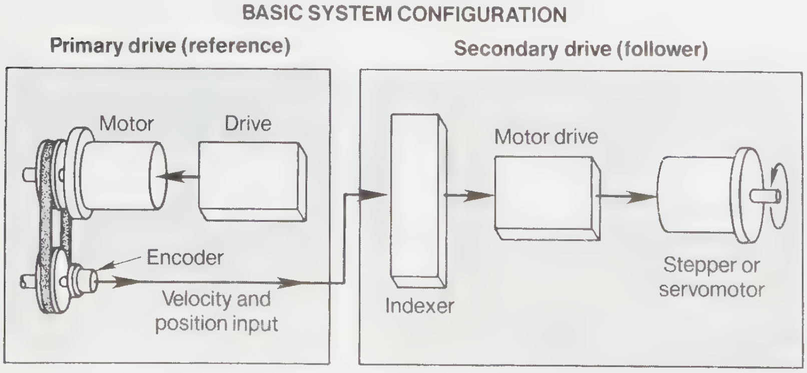
Motor-follower — electronic gearing

Encoder tracking is a technique that monitors a reference motor with an encoder and controls a secondary motor. The method provides programmable motor-to-encoder ratios that determine relative speed between two axes. A dynamic change in ratio produces acceleration or deceleration.

Absolute motion-control profiles are normally set for a predetermined number of encoder and motor steps. But indexers can delay a secondary profile from a reference by a certain number of encoder steps, in either a fixed or dynamically changing manner. Compared to the reference motion, the secondary motion profile can be made as simple or as complex as needed. Applications for encoder tracking include electronic gearboxes, conveyor belts, electronic cams, and web processors.

Many control applications require the coordination or synchronization of two or more axes of motion in a specific pattern. The most familiar example is found in X-Y plotters, but simultaneous motion in two axes need not always describe a plane figure. Control of constant speed ratio between two pumps or the motion of a welding head with respect to a moving conveyor belt are other examples. However, these examples all require that the motion profile of a second axis be based on the position, speed, or acceleration of a reference axis.

Before the introduction of tightly coupled indexers, primary and secondary motion profiles were specified individually. As a result, small deviations or errors from an ideal profile described for the primary reference axis often resulted in a gradual drift between secondary and primary motion. But in


BASIC SYSTEM CONFIGURATION
Primary drive (reference)
Secondary drive (follower)
Motor
Drive
Encoder
Velocity and position input
Motor drive
Indexer
Stepper or servomotor

A basic indexer or follower is directly coupled to the drive shaft of the primary motion system with an incremental encoder. The secondary servomotor either follows the primary position and velocity exactly or it follows a complex profile constructed by programming several move segments end to end. The user defines the task for the secondary motor's drive shaft.

programming the indexer, the absolute motion profile of the secondary axis is not specified. Instead, the indexer is programmed in terms of ratio, offset, or more complex relationships between the measured (reference) motion and the controlled (secondary axis) motion. This eliminates the need for precise absolute motion specifications for both the reference and secondary motion profiles.

A typical control system consists of an incremental, quadrature output encoder, an indexer, and a secondary motor-drive system. The incremental encoder is connected to the primary reference motion with a direct shaft coupler, belt and pulley, or rack and pinion.

The indexer receives position and velocity data from the reference encoder every 10 ms or less frequently. The indexer then provides step and direction data to the secondary motor-drive system based on the incoming encoder steps and the programmed move sequence. The secondary drive system translates the step and direction signals into controlled shaft position.

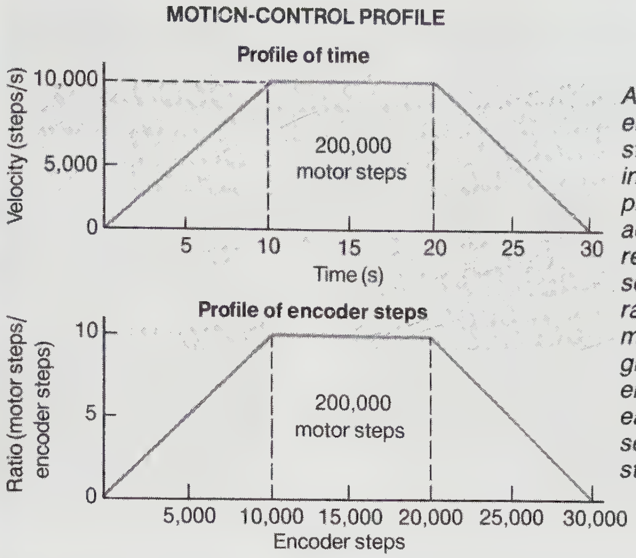
Consider an encoder producing steps at a rate of 1,000 Hz in the positive direction. If the ratio is 2:1, the indexer's output will be 2,000 Hz in the positive direction. If the ratio is zero, the output will be 0 Hz. Likewise, if the ratio is −2:1, the output will be 2,000 Hz in the negative or opposite direction. Without changing ratio, if the reference speed drops to 500 Hz, the secondary axis follows at 500 Hz positive, 0 Hz, and 500 Hz negative.

The ratio is changed by program statements unique to each segment of a profile. A segment is defined by the number and ratio of motor steps to encoder steps it covers. The indexer changes ratios instantly or gradually, over a user-defined number of encoder steps. This allows the controlled motor to accelerate or decelerate to a new ratio without stalling while the reference axis maintains a constant speed.

In many applications, move profiles are created by defining and piecing together several move segments. For applications in which the total number of motor and encoder steps covered is critical, defining segments allows a more precise profile specification than simply ramping to new ratios.

A motion-control profile based upon encoder speed is illustrated by either a profile as a function of time or as a function of encoder steps. The first shows the X-axis as time in seconds, and the Y-axis in velocity or motor steps per second. The velocity ramps from zero to 10,000 steps/sec over 10 sec, stays at 10,000 steps/sec, and ramps back to zero over 10 sec. The ratio is velocity, the change in ratio is acceleration, and the total distance covered over 30 sec is the area under the profile, or 200,000 steps.

The second shows the X-axis as encoder steps and the Y-axis as the ratio of motor steps to encoder steps. This ratio ramps from zero to 10 over 10,000 encoder steps, remains at 10 for 10,000 encoder steps, and ramps back to zero over another 10,000 encoder steps. The total number of motor steps covered during 30,000 encoder steps, regardless of encoder speed variations, is the area under the curve, or 200,000 steps. If the encoder produced 1,000 steps/sec, the two profiles would exactly match over the same 30-sec period. ■



A profile based upon encoder speed or steps/s over a time interval is programmed to achieve the same results as a system set up in terms of the ratio of encoder to motor steps for a given number of encoder steps. In each case, the secondary motor steps 200,000 times.

NEW FROM VOLKMANN. THE VERSATILE AD-2. AFFORDABLE QUALITY DRIVES FOR LOW TO MID FREQUENCY APPLICATIONS.

Volkmann makes choosing the right low-to-mid frequency drive for your special applications easy. No worries about reliability with Volkmann's new AD-2. All the features you associate with standard drives...plus many extras, including:

- Compact NEMA 12 enclosure.
- Easy to read digital display.
- Easy to use programming–simple start-up without using the manual
- Oversize key pads for big hands with gloves
- Volkmann's unique 2 year warranty and service program
- Made in USA.

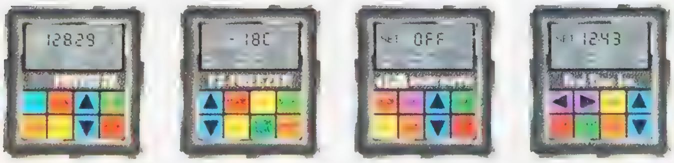
We continue our 15 year tradition for performance, quality and reliability. Our application engineers, field sales representatives and service staff are on call to help you with your special application requirements.

VolkmannAD-2
GRASEBY VOLKMANN CORPORATION

For information and our AD-2 brochure, call or write Bill Weil, Sales Manager
99 Aldon Road, Concordville, PA 19331 • Phone: 215-459-4300 Fax: 215-459-4302

Circle 386

Mallory's New Universal Electronic Controller. It's Programmed To Your Specs.



You now have control over your controller.

Because Mallory's new Universal Electronic Controller can be tailored to your specific needs, and for a wide range of control functions.

In fact, you tell us what your needs are.

Then, we'll write the operating software and adapt the keypad and annunciator messages based on your application. There's capability for 8 switched outputs, 8 analog inputs, and 8 digital I/O's for monitor and control.

The UEC controller does the job of many. Which lets you build in more flexibility, capability, and more value into your OEM designs.

Go ahead, tell us.

Tell us what your control needs are. And we'll show you how the UEC can meet them. Efficiently and ec nomically. Call Mike Williams **1-317-328-4062** to arrang demo in your facility.

Another design advantage is the UEC's compactness.

MALLORY

MALLORY CONTROLS
2831 Waterfront Parkway, East Drive
Indianapolis, IN 46214
(317) 328-4010
FAX (317) 328-4244

Division of Emerson Electric Co

Circle 387

Input/output devices

Input/output devices are the interface between the controller and the controlled system. Input devices convert physical quantities to electrical signals, while output devices allow the controller to act on the system.

The electronic brains in control systems depend on a network of input/output devices. These devices tie the controller to the outside world by supplying it with physical data and allowing it to act on the controlled system. Smart sensors and smart power ICs do more than just provide access, they also share processing and decision-making tasks as well.

Input devices include transducers, sensors, and switches. Sensors and transducers convert physical data such as speed, position, temperature, acceleration, and pressure into electrical signals that are recognized by the controller. Switches allow operators to supply information that supplements or overrides input data.

Output devices include power semiconductors and ICs, relays, and circuit breakers. By providing control over electrical power subsystems that drive motors and solenoids, they allow the controller to initiate, halt, or modify action in the controlled system.

Sensors and transducers

Position and velocity sensors are common in industrial and automotive applications. Position sensors span a broad spectrum. Virtually all closed-loop motion-control systems use one. Velocity sensors or tachometers also are widely used. Other sensors are used to measure pressure, temperature, and acceleration.

Factory automation, in particular, requires linear and rotational position-measuring transducers. These demands and a need for digital interfacing are being met by position transducers such as synchros, resolvers, optical shaft encoders, linear-variable differential transformers (LVDTs), and potentiometers.

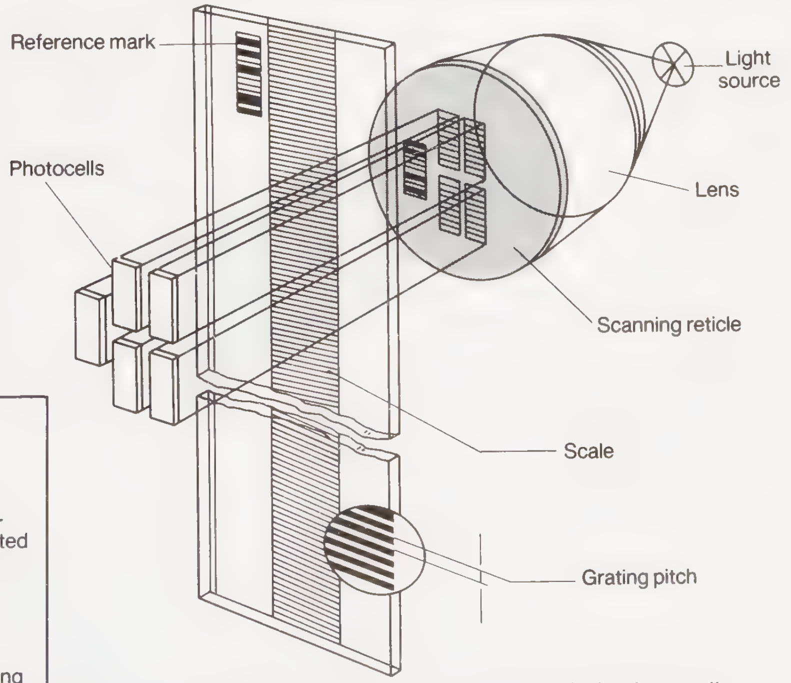
Linear encoders

A typical linear encoder consists of a scanning unit and a scale. The scale is generally glass and is cemented to a support, usually an aluminum extrusion. The scanning unit contains a light source, photocells, and a second graduated piece of glass called the scanning reticle. This scanning reticle sits a short distance from the scale.

In operation, a parallel beam of light produced by the light source and lens passes through four windows on the scanning reticle, through the glass scale, and onto a set of photosensors. When the scanning unit moves, the scale modulates the light beam, creating sinusoidal outputs from the photosensor.

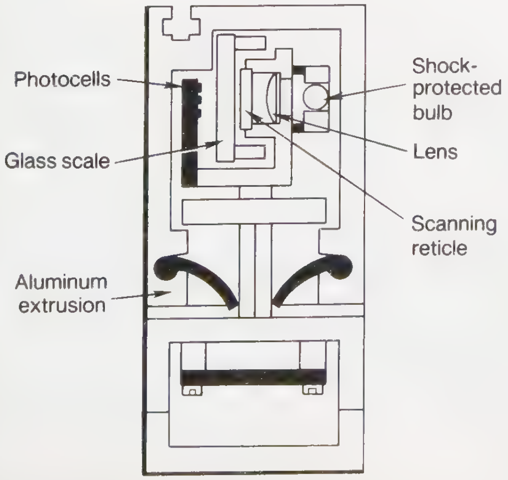
The four windows in the scanning reticle are each phase shifted 90° apart. The system combines the phase-shifted signals to produce two symmetrical sinusoidal outputs phase shifted from each other by 90°. A fifth pattern on the scanning reticle has a random graduation that, when aligned with an identical pattern on the scale, creates a reference signal.

BASIC OPTICAL LINEAR ENCODER COMPONENTS



Basic photoelectric encoder components include photocells, a scanning reticle, light source, and movable grating. Industrial encoders also include extra features to promote ruggedness such as shock-mounted lamp sockets and ball bearings for shaft-mounted units. When configured in a rotary encoder, the grating is made from vacuum-deposited chrome on a transparent disc.

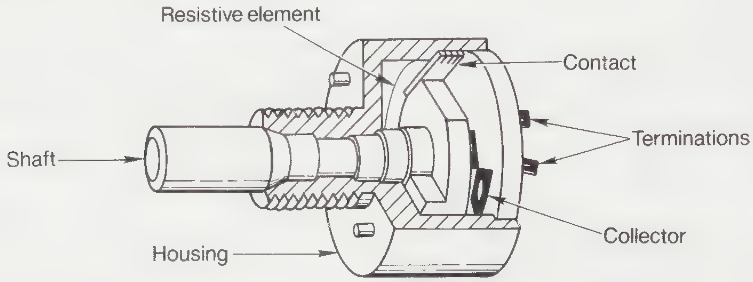
LINEAR ENCODER CROSS SECTION



POTENTIOMETRIC POSITION SENSORS

In potentiometric position sensors, high-temperature conductive plastic film acts as a resistive element. A precious-metal contact wipes the surface and is welded to a slip or collector ring. Wiper output is fed to terminations on the rear of the housing.

Output functions are obtained by adjusting the width of the resistive material because output resistance is proportional to resistor width. Linear output functions with different slopes and offsets are common.



To obtain high resolution, a very fine scale pitch is used. Because of the diffraction effects of the scale grating, spacing between the fixed scale and scanning reticle must be extremely narrow and constant. Consequently, the entire scanning unit mounts on a carriage that runs on ball bearings along the glass scale. The scanning unit connects to the machine slide via a coupling that compensates for alignment errors between the scale and the machine guideways.

In linear encoders for NC applications, external electronics interpolate the sinusoidal signals from the encoder head. The effect is to subdivide the basic line spacing on the scale to gage smaller increments of motion.

Standard encoders using this principle come in a variety of form factors. Some units have small exterior dimensions while others fasten along the length of the scale with screws, permitting higher accuracy (up to ±2 μm/m). These encoders may incorporate a mechanical corrective device, which contains correction points at 100-mm (4-in.) intervals. This feature allows compensation for errors caused by imperfections in the guideways.

Encoders described above are limited to measuring lengths of about 3 m or so. Encoders that measure longer distances contain scales made from steel tape. A typical tape is about 0.3 mm thick and contains a grating of highly reflective gold lines with a pitch of about 100 μm.

In operation, a small carriage runs along the tape and holds a photoelectric scanning unit. The unit also contains error compensation devices every 300 mm (8 in.). Additional compensation is possible through appropriate tensioning of the steel tape. The steel tape can be made in lengths of 100 m and can be rolled into a coil. The scale housing is assembled in segments. After the housing is assembled, the tape scale and sealing lips are inserted in one piece.

To provide a resolution of 1 μm from a pitch of 100 μm, the signals must be interpolated by a factor of 25. The maximum traversing speed of the encoder is set by the maximum scanning frequency (in scanned signal cycles per second). This, in turn, depends on the interpolation factor. Also important is the minimum pulse edge distance that the controller can process. The maximum speed is 30 to 90 m/min, or about 100 to 300 fpm.

New systems have been developed to allow smaller measuring steps. These use circuits that provide 10×, 25×, or 50× interpolation. When used with counters that count rising and falling edges of quadrature square waves, these systems can measure steps of 0.5 μm or 0.1 μm when used with a 20-μm pitch.

High-resolution encoders can be either sealed from contamination or exposed. Exposed linear encoders have been used for several years on precision jig borers, grinding machines, and stages. These encoders consist of a glass scale and a noncontacting scanning head. In this way, coupling error and other mechanical errors are eliminated and a resolution to 0.05 μm (about 2 μin.) is possible.

Naturally, exposed instruments must be protected from environmental contaminants. This is a problem for the designer of the equipment on which en-

UNDERSTANDING INTERPOLATION

The interpolation process becomes clear by examining the case where the resolution of a linear encoder increases by a factor of five.

The two scanning signals A and B from a linear encoder can be represented by

$$A = U_o \sin\varphi$$
$$B = U_o \cos\varphi$$

where U_o is a constant, $\varphi = 2\pi X/C$, where X = linear movement and C = signal cycle. Interpolation of each signal by five yields ten signals that are represented by

$$\begin{aligned} U_1 &= A\cos\beta_1 + B\sin\beta_1 \\ &= U_o(\cos\beta_1 \sin\varphi + \sin\beta_1 \cos\varphi) \\ &= U_o \sin(\varphi + \beta) \end{aligned}$$

where $\beta_i = i \times 18°$ and $i = 0, 1,..,9$.

These ten sinusoidal signals are synthesized by a phasing network, which also transforms them into square waves. The square waves are then combined to form two square-wave pulse trains (in quadrature) with a frequency five times that of the original sine waves.

These signals are transferred to a counter that may be integrated into a motion-control system. Because counters generally count both the rising and falling edges of both square waves, the resulting resolution of the transverse movement is $C/20$.

Signal-processing electronics also transforms the reference signal into a square wave and combines it with the 5× encoder signals to produce a one-step square-wave pulse. This pulse can be used to determine the absolute position of the encoder.

Some things Parker doesn't seal . . .

ut, if you need ffective EMI/RFI hielding and nvironmental sealing olutions...

Ve design them, abricate them, nd deliver them.

The egg is perhaps the world's most efficient packaging. We at Parker wouldn't presume to try to improve on it. For EMI/RFI shielding and environmental sealing needs however, Parker has the knowledge and the product resources to get the job done.

From a simple Parshield conductive O-ring to ultra-sophisticated electronic enclosure seals, Parker has a Parshield conductive elastomer product that's designed for your application.

Parker's extensive environmental sealing experience, combined with the superior physical properties of Parker Parshield conductive elastomer products cover virtually every EMI sealing/shielding situation you could imagine. . . and we have the engineering expertise and manufacturing capability to custom design and fabricate almost any type of elastomeric EMI/RFI shielding or sealing device you'll ever require.

Parker Parshield products offer you superior performance in the areas of shielding, corrosion protection, long term thermal stability, and cost reduction whether your application is EMI/RFI/EMP/ESD, galvanic, NBC, environmental, vacuum, pressure or thermal.

Parker Parshield conductive elastomers are fully qualified where required, to all MIL-G-83528 specifications and types.

To learn more about Parker's unique capability to solve your EMI shielding and sealing problems, ask for your FREE copy of Parker Seal Brochure PSG2700 "PARSHIELD CONDUCTIVE ELASTOMERS" today. Contact:

PARKER SEAL GROUP
2360 Palumbo Drive
Lexington, KY 40509
(606) 269-2351 or (606) 268-5074
FAX: (606) 268-1989

f you have an EMI shielding r environmental sealing roblem, make it ur problem...that's what ve're here for. We're Parker... he shielding and sealing people!

Ask for your FREE copy today!

Parker Seals

PSG2700

PARSHIELD CONDUCTIVE ELASTOMERS

Parker Seals...when you can't afford second best!

Circle 288

ABSOLUTE RESOLVERS

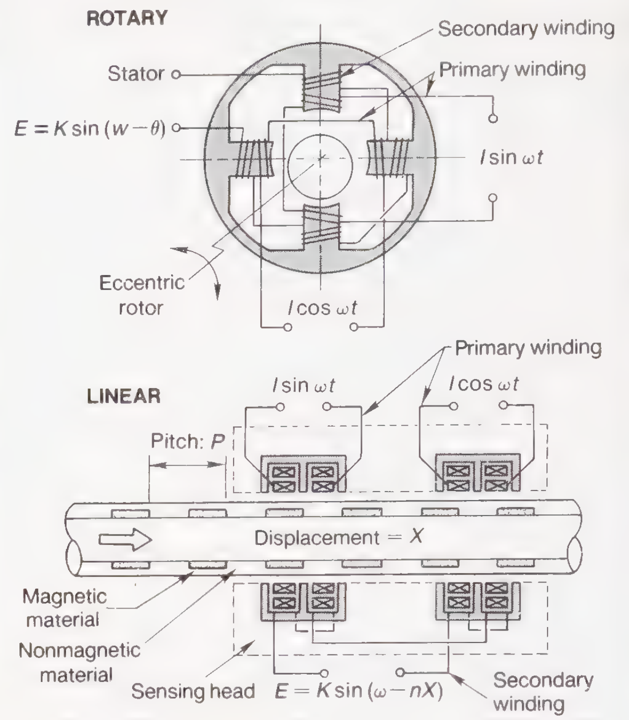
While most resolvers are incremental, absolute encoders are available in both rotary and linear versions. These encoders are often simpler than standard optical encoders. For example, the rotary design has only one moving part, an eccentric rotor fixed to a shaft supported by bearings.

A stator containing primary and secondary windings fits around the rotor. The design eliminates brushes, LEDs, optical discs, and electronic components, all of which are normally subject to wear.

The eccentric rotor changes the current phase relationship between the primary and secondary windings. Unlike optical devices, the sensor output is analog and not affected by power loss or noise. A converter decodes the phase information and converts it into Gray or binary code. It can be located up to 100 m away from the sensor.

Basic accuracy is about ±3°. For applications requiring a higher resolution, a toothed rotor is used.

In the linear version, an alternating sequence of magnetic and nonmagnetic materials in the rails changes the phase between the coils. Various versions have resolutions from 16 to 64 mm.



coders are installed. The designer must also plan how to align the encoder optimally in the individual axes so the high accuracy of the encoder is transmitted to the workpiece. A final concern is to provide easy accessibility for assembly.

Magnetic encoders are a viable alternative to optical types because they are inherently rugged and operate reliably under shock and vibration, at high temperature, and in contaminated and humid areas. Hall-effect and magnetoresistive devices are two sensors commonly used for these conditions, and motor speed and positional accuracy dictate which of the two is better suited for an application.

The magnetic encoder wheel in these devices is usually made from an injection-molded ferrite with an array of poles embedded near the surface. A 15-mm encoder contains a 7.6-mm-diameter wheel, magnetized with 32 poles (16 north and 16 south) using a static fixture. Fixture size typically limits the number of poles that can be embedded. The pole pitch for a 32-pole motor is about 0.75 mm, the smallest practical size a fixture can handle.

Hall-effect encoders usually switch with an output characterized by hysteresis. They switch when the magnetic field from the rotating encoder wheel reaches a flux density sufficient to overcome a critical threshold level. Likewise, when the detected field reaches a flux density below a lower threshold level, it switches back to the previous state. Consequently, Hall sensors containing 32-pole encoder wheels generate 16 pulses per revolution. Today, however, higher resolution is needed from miniature encoders.

The need for higher resolution is being met by encoders using magnetoresistive material that lowers its bulk resistance by about 1.6% in the presence of a saturating magnetic field. Magnetoresistive sensors differ from Hall-effect sensors in two important ways. First, the saturating field is in the range of 0.003 to 0.005 T, an order of magnitude smaller than typical switching fields for digital Hall sensors. This detection level makes the magnetoresistor a much more sensitive measuring device.

Second, the change in resistance is independent of magnetic field polarity, so the 32-pole wheel generates 32 pulses per revolution, twice the resolution of previous sensors.

A magnetoresistive sensor assembly comprises an array of thin nickel-iron permalloy strips. Strip width is much greater than thickness. The sensor is located above the magnetic track of the encoder wheel with the strips parallel to the wheel axis.

One channel of a magnetoresistive sensor consists of two strips displaced one-half pole pitch from each other. They are connected differentially to double the sensor's output voltage. As the encoder wheel rotates past one pole (two sensor strips), the output voltage completes one cycle, generating a 40-mV peak-to-peak signal from a 5-Vdc power supply.

Resolvers and synchros: Resolvers and synchros perform well where small size, long-term reliability, absolute position measurement, and high accuracy are required. Typical synchros and resolvers resemble small cylindrical ac motors. Diameters vary from 0.5 to 3.7 in. One end of the body contains an insulated terminal block; the other a mounting flange. Rotor shafts are normally threaded and splined.

The simplest devices employ single-

Comparing position transducers

Transducer type	Absolute accuracy	Typical cost	Comments
High-accuracy absolute optical encoders	1.2 arc seconds	$10,000	Binary output.
Rotary Inductosyns	1.5 arc seconds	$3,000	Includes $900 digital converters.
High-accuracy resolvers/synchros	7 arc seconds	$2,000	Includes $900 digital converter.
Medium-Accuracy optical	23 arc seconds	$2,500	Binary output.
Selected resolvers/synchros	3 arc minutes	$425	Includes $255 digital converter.
Standard resolvers/synchros	7 arc minutes	$340	Includes $255 digital converter.
Potentiometers	8 arc minutes	$125	Does not include digital converter.
Typical absolute optical encoders	11 arc minutes	$400	Binary output.
Typical incremental optical encoders	11 arc minutes	$200	Pulse output.
Absolute contact encoders	26 arc minutes	$675	Binary output.
Incremental contact encoders	26 arc minutes	$450	Pulse output.

DRC MAKES LATE DELIVERIES OF MODULAR ENCODERS OUTDATED

Our shipping department professionals have a commitment to quality work. With every on-time shipment of our modular encoders, they have established a delivery record our customers can depend upon. They understand that today's highly competitive marketplace requires them to provide fast delivery response to customers' everchanging needs. DRC's broad selection of standard, off-the-shelf models can be shipped in 3 days. We also react quickly to more specialized configurations. Our team continually strives to exceed our customer's expectations.

We, at DRC, have made each aspect of our business a building block in defining us as a quality vendor. From defect-free products to fast customer service, along with custom designs and quick, on-time delivery...each plays a part in establishing the type of relationship you, our customer, want with your suppliers. DRC's commitment to the quality of that relationship, not only will be met, but we hope surpassed. Let us be partners with you in helping build quality into your products and into your business.

DRC-WHERE QUALITY IS BUILT-IN

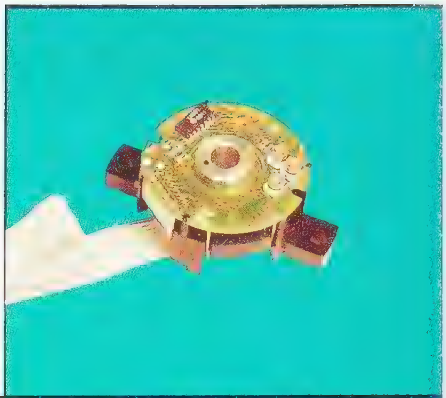
Call DRC for applications assistance and delivery at 1-800-323-4143

ENCODER DIVISION

DRC®
DYNAMICS
RESEARCH
CORPORATION
60 Concord St., Wilmington, MA 01887

MADE IN USA

DRC offers standard off the shelf modular encoders with 3 day shipment and 2 year guarantee.



SPECIFICATIONS — TK730/731

Maximum Disc Resolution:	1250 cycles per/revolution
Maximum Output Resolution:	5000 counts per/revolution (See note 1)
Light Source:	GaAlA's L.E.D. rated at 100,000 hrs M.S.
Excitation Voltage:	+5VDC
Symmetry Specifications:	180 ± 10 (at 10KHz)
Frequency Response:	50KHz channel 10KHz ZR
Quadrature Specifications:	90 ± 20 at 10KHz
Output Types:	730-Single ended TTL 731-diff TTL linedriver
Mechanical Dimensions:.	See Outline Dimensions
Operating Temperature:	0 to 70°C (32°F to 158°F)

ORDERING INFORMATION

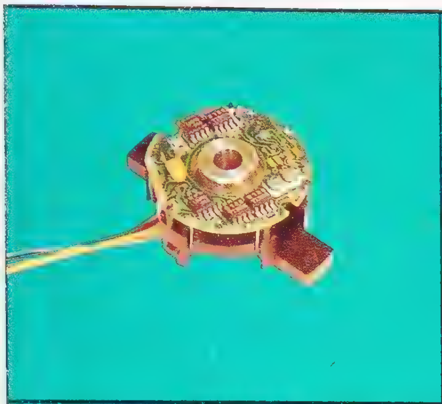
Standard TK730 units have single-ended TTL output with zero reference and 18″ ribbon cable terminated with 10 pin connector. Hub sizes are 4E = ¼″, 6E = ⅜″, and 8E = ½″.

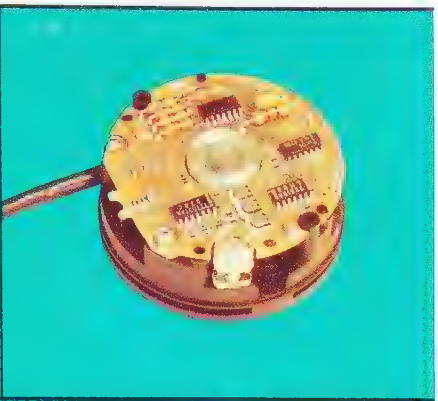
Standard TK731 units have RS-422 compatible line driver output with zero reference and 18″ ribbon cable terminated with 10 pin connector. Hub sizes are 4E = ¼″, 6E = ⅜″, and 8E = ½″.

PRICING

These units are shipped in 3 days. Call DRC for quick delivery and competitive pricing on our other models.

	Quantity	
Model	1-9	10-24
TK730-4E21-500-A	$ 95	$ 87
TK730-4E21-1000-A	$ 95	$ 87
TK730-4E21-1024-A	$ 95	$ 87
TK730-6E21-500-A	$ 95	$ 87
TK730-6E21-1000-A	$ 95	$ 87
TK730-6E21-1024-A	$ 95	$ 87
TK730-8E21-500-A	$ 95	$ 87
TK730-8E21-1000-A	$ 95	$ 87
TK730-8E21-1024-A	$ 95	$ 87
TK731-4E21-500-A	$108	$ 99
TK731-4E21-1000-A	$108	$ 99
TK731-4E21-1024-A	$108	$ 99
TK731-6E21-500-A	$108	$ 99
TK731-6E21-1000-A	$108	$ 99
TK731-6E21-1024-A	$108	$ 99
TK731-8E21-500-A	$108	$ 99
TK731-8E21-1000-A	$108	$ 99
TK731-8E21-1024-A	$108	$ 99





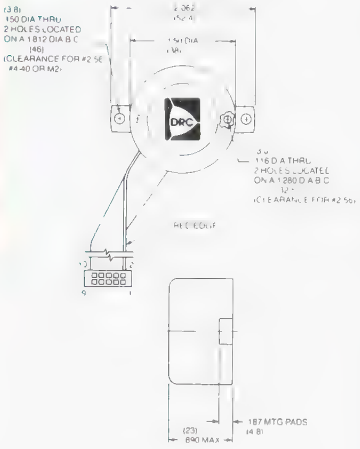
TK830	T23
1250 cycles per/revolution	2540 cycles per/revolution
5000 counts per/revolution (See note 1)	10160 counts per/revolution (See note 1)
GaAlA's L.E.D. rated at 100,000 hrs M.S.	GaAlA's L.E.D. rated at 100,000 hrs M.S.
+5VDC	+5VDC
180 ± 10 (at 10KHz)	180 ± 10 (at 10KHz)
Up to 200 KHz	Up to 100KHz
90 ± 20 at 10KHz	90 ± 22 at 10KHz
Single ended TTL (LM339)	OC, TLD, CLD, AS (See note 2)
See Outline Dimensions	See Outline Dimensions
0 to 70°C (32°F to 158°F)	0 to 70°C (32°F to 158°F)

Standard TK830 units have single-ended TTL output with zero reference and 18″ ribbon cable terminated with 10 pin connector. Hub sizes are 4E = ¼″, 6E = ⅜″, and 8E = ½″.	Standard T23 units have RS-422 compatible line driver output with zero reference and 18″ shielded cable. Hub sizes are 4E = ¼″, 6E = ⅜″, and 8E = ½″.

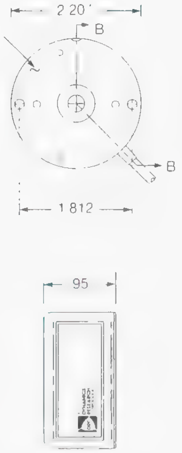
	Quantity			Quantity	
Model	**1-9**	**10-24**	**Model**	**1-9**	**10-24**
TK830-4E21-500-A	$108	$ 97	T23BA4ECB16-2500	$134	$127
TK830-4E21-1000-A	$108	$ 97	T23BA6ECB16-2500	$134	$127
TK830-6E21-500-A	$108	$ 97	T23BA8ECB16-2500	$134	$127
TK830-6E21-1000-A	$108	$ 97	T23BA4ECB16-2540	$134	$127
TK830-8E21-500-A	$108	$ 97	T23BA6ECB16-2540	$134	$127
TK830-8E21-1000-A	$108	$ 97	T23BA8ECB16-2540	$134	$127

OUTLINE DIMENSIONS

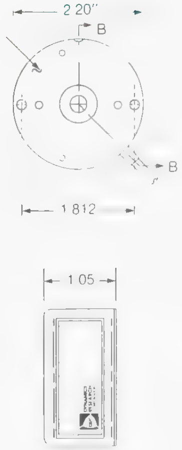
TK730/731, TK830



T23 A



T23 B



Notes:

1. Maximums are specified after edge triggering of quadrature square waves by customer external electronics i.e. an encoder producing 500 cycles/revolution can provide 2000 counts/revolution.
2. OC = open collector, TLD = TTL line driver, CLD = CMOS line driver, AS = amplified sinewave

Specifications subject to change without notice.

Modular encoders with 1.5" and 2.1" diameter and 50 to 10,160 counts per revolution

DRC HELPS YOU BUILD QUALITY INTO YOUR PRODUCT

From the first contact with our sales team to on-time shipment of your optical encoder order, DRC's commitment is to help build quality into your product. The long term reliability of our encoders is backed by a 2 year guarantee. All DRC encoders are 100% tested to insure your order is defect-free.

DRC's broad product line insures success in selecting an encoder to meet you needs. With over 35 years of optical encoder experience, DRC has the knowledgeable staff to provide the support for all your encoder application problems an custom encoder designs. We provide quick delivery of units for you to evaluate on consignment. In production volumes, our leadtimes are generally 4 weeks and under. DRC's large selection of standard off-the-shelf encoders are offered with 3 day delivery. We have a dedicated goal o total customer satisfaction and to helping build quality into your products.

DRC-WHERE QUALITY IS BUILT-IN

Call DRC for applications assistance and delivery at 1-800-323-4143

ENCODER DIVISION

DRC DYNAMICS RESEARCH CORPORATION
60 Concord St., Wilmington, MA 0188

MADE IN USA

winding rotors that revolve inside fixed stators. Synchros contain a stator with three windings located 120° apart and electrically connected in a Y-configuration. Resolvers differ from synchros in that their stators contain only two windings mounted 90° apart.

Synchros and resolvers resemble rotating transformers during operation. The rotor winding is typically excited by an ac reference voltage at frequencies ranging up to a few kilohertz. The magnitude of the voltage induced in any stator winding is proportional to the cosine of the angle between the rotor-coil axis and the stator-coil axis.

In synchros, the voltage induced across a pair of stator terminals is the vector sum of the voltages across the two connected coils. For example, if a reference voltage $V\sin(\omega t)$ excites the rotor of a synchro, then the stator voltage will be

$$V(S_1 \text{ to } S_3) = V\sin(\omega t)\sin(\theta)$$
$$V(S_3 \text{ to } S_2) = V\sin(\omega t)\sin(\theta + 120°)$$
$$V(S_2 \text{ to } S_1) = V\sin(\omega t)\sin(\theta + 240°)$$

where θ is the shaft angle.

Resolvers, on the other hand, will have stator terminal voltages of

$$V(S_1 \text{ to } S_3) = V\sin(\omega t)\sin(\theta)$$
$$V(S_4 \text{ to } S_2) = V\sin(\omega t)\cos(\theta)$$

Resolver-to-digital converters transform these voltage relationships into digital representations of the actual angle θ.

When combined with such converters, synchros and resolvers can provide 12-bit resolutions of 5.3 arc-minutes. Absolute accuracies approach more than 20 arc-seconds for higher resolution models. Attaching a resolver to a 0.1-in. pitch lead screw and using a 12-bit converter provides 25-μin. linear resolution.

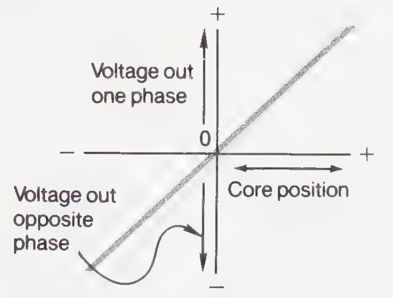
Synchros and resolvers can also perform linear position measurements by employing lead screws. Alternatively, Inductosyns measure linear position directly, and because Inductosyns offer high accuracy and ruggedness, they are often used in severe industrial environments.

LVDTs: An LVDT provides position feedback using mutual inductance between primary and secondary windings. A moveable core couples the excitation voltage in the primary to the two secondaries. Phase and amplitude of the secondary output voltage vary with the position of the magnetic core.

The amplitude of the secondary voltage is proportional to the magnitude of position. The phase indicates the position of the core relative to the null.

With the core centered between the two secondaries, at the null position, secondary voltages have equal amplitudes and are 180° out of phase. The net voltage across the secondaries is zero. As the core moves toward positive full scale, the amplitude of the in-phase sinewave increases. As the core moves toward negative full scale, the amplitude of the 180° out-of-phase sinewave increases.

LVDTs used in applications such as aviation have either dual or quadruple redundancy. Some units have a mean time between failure of almost three million hours; over 300 years. That kind of reliability results from good design and construction practices. Many manufacturers use Inconel or stainless-steel housings, electron-beam welding, and spherical bearings to reduce rod misalignment. And because the coils are wound by computer control, unit interchangeability is high.



LVDT output voltage varies linearly with core position. As the core passes through a null position, the output undergoes a phase change.

The primary limitation is the full-scale displacement. This is the maximum distance the core travels without a serious decrease in linearity. The linear operating range is twice the full-scale displacement since the core can travel in either direction from the null position. The actual linear range will always equal or exceed the nominal value.

Linearity is the deviation from an ideal straight-line response. The output voltage of an LVDT is a function of the core displacement and is a straight line within a specified range. Beyond the nominal range, the output begins to deviate from a straight line in a gentle curve. Linearity is given as a percentage of reading. Linearity is inherent in the transducer and largely determines the absolute accuracy.

LVDT nonlinearities are typically 0.25%. Precision units have maximum nonlinearities of 0.05%. For example, an LVDT with a 0.25% nonlinearity and output of 0.39 mV/V/mil, with a 1.0 V_{rms} excitation and 390 mV_{rms} full-scale output, will exhibit a maximum nonlinearity of 2.5 mil.

Linearity can be improved by using an LVDT at less than the nominal range. Conversely, an LVDT can be used beyond the nominal range where linearity is not important. The range sets the full-scale output of the LVDT. This is matched to the full-scale output range of the LVDT-to-digital converter.

Optical shaft encoders

Rotary and linear optical encoders are common in position and motion sensing. Here, a disc or plate containing opaque and transparent segments moves between an LED and detector to interrupt a light beam.

All rotary encoders consist of a light source, light detector, code wheel, and signal processor. There are two basic encoder styles: absolute and incremental. Absolute encoders contain multiple detectors and up to 20 tracks of segment patterns. For each encoder position, there is a different binary output. Therefore, shaft position is absolutely determined.

Often, the tracks on absolute encoders are arranged to produce a binary output called Gray code. The advantage of Gray code over straight binary is that only one bit changes at a time. Thus, the maximum error (if the encoder stops halfway between transitions) is only 0.5 bit. In absolute encoders, this information is available even if the encoder is turned off and on. This makes them suitable for low-speed applications, as in telescopes, or where the encoder may be temporarily shut down, as in highway bridges.

Absolute encoders are available in single and multiturn versions. Multiturn devices are primarily used with measuring screws.

When low cost is important, or when only relative position is needed, incremental encoders are preferred. Their output typically consists of two square waves. Each square wave pulse corresponds to an increment of rotation. Often, incremental encoders have a third channel with a single segment slot. This is called the reference slot and is used to zero or home the device.

Single-channel encoders, also called tachometers, are inherently less accurate than dual-channel encoders and cannot register direction. Inaccurate readings often result when the code wheel stops on or near a slot's edge and vibrations move the code wheel back and forth. If the slot edge interrupts the light beam, the counter increments with each transition.

Other common encoder versions include standard, modular, and kit.

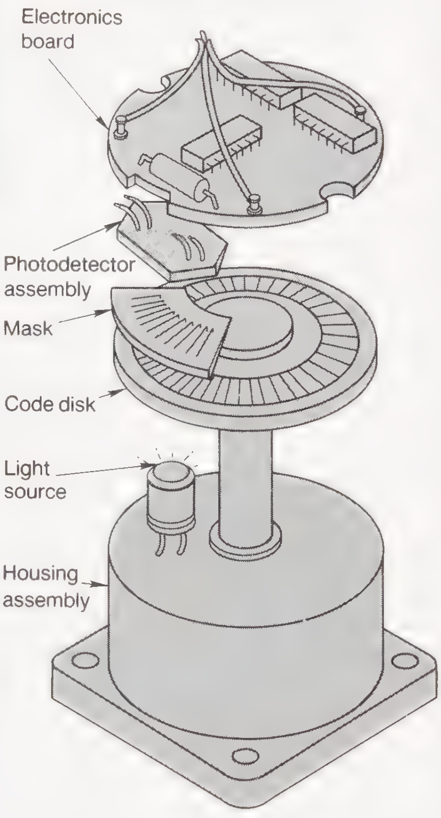
SHEDDING LIGHT ON OPTICAL ENCODERS

Optical encoders typically use LEDs or high-reliability lamps as light sources. LEDs provide over 100,000 h of life and withstand appreciable shock and vibration. Moreover, their small size allows them to operate as a point source, supporting high-resolution measurement.

High-reliability lamps are also used because they offer a 400% signal gain over LEDs. (Improved high power LEDs may reduce this advantage, however.) Military lamps provide increased reliability and 40,000-hr lifetimes (tested at over 100,000 hr). Their increased signal level helps to widen the effective spacing between disk and grating. Mil-rated lamps can be used in optical encoders rated for shock up to 11 ms at 50 g, and for vibration levels of 20 g from 5.0 to 2 kHz over three directions. Lamps also perform better than LEDs at high temperatures. For severe environments, fiber optics can be used to locate light emitters, detectors, and signal-processing electronics away from the code disk and plate.

To increase the line sharpness seen by the photodetector, encoders commonly use a stationary mask between the code wheel and detector. But multiple photodiode detectors eliminate the need for a mask and result in an encoder with more tolerance for axial play and runout.

INSIDE AN ENCODER



Standard encoders are those that have their own shaft and bearing assembly. The encoder shaft couples to the motor shaft with a belt, coupling, or gear train. Hollow shaft encoders are similar, but the motor shaft fits into the encoder shaft bore.

Some manufacturers claim there is a difference between modular and kit encoders, but others say they are the same. Some say that a modular encoder is complete and ready to use, while kit encoders require user assembly. Regardless of the amount of assembly, both fit directly on the motor shaft. A setscrew usually secures the code wheel to the shaft, but some designs have press-tight fittings.

While standard and hollow shaft encoders are the most rugged, modular encoder makers say that users can easily make these devices more environmentally sound by simply mounting a bell or can over the encoder to keep out contaminants.

Examining a modular rotary encoder used on a servomotor reveals a code wheel attached directly to the motor shaft. This makes the encoder sensitive to motor shaft run-out and axial movement. A large amount of play can break the code wheel or push it into the stationary parts of the encoder, forcing the optics out of alignment. These problems beset even large, high-resolution encoders that sometimes cost as much as the motor they attach to.

However, newer modular encoders are less likely to suffer from these problems. These devices, sold as kits that assembly piecewise onto a motor shaft, eliminate some of the components that cause run-out problems. The new encoder designs have a lower part count as well, reducing costs and, in the process, making closed-loop control practical for many cost-sensitive applications.

Surprisingly, the use of encoders with a larger gap between the code wheel and housing may enable certain applications to use less expensive motors that exhibit appreciable shaft play. If the encoder can also withstand high temperatures (above 70°C), the motor may also be sized smaller and run hotter than would otherwise be acceptable.

Most improvements in modular encoders concern the encoder optics and electronics. For example, until recently, encoder light emitters (usually LEDs) and detectors were relatively large compared with the slots in the disk. As a result, a stationary mask has been needed between the detector and code wheel. The mask increases accuracy by sharpening the edges of the light pulses falling on the detectors.

However, the mask itself presents problems. For one, it increases component and assembly costs. It is also the stationary component that lies nearest the spinning disk, thereby increasing the chance of interference. And the mask attenuates light reaching the detector.

To solve these problems, several manufacturers have designed encoders that need no mask. Eliminating the mask allows more space between the disk and detectors, increasing the tolerance for phase error and edge jitter between channels. The key developments that make maskless encoders feasible are miniaturized LEDs and detectors, and the use of special lenses.

Elimination of the encoder mask entails drawbacks as well as advantages. The biggest drawback is that detectors on maskless encoders can only work with specific code-wheel resolutions. But encoders with masks can be adjusted to fit wheels having different resolutions. Where nonstandard wheels are needed, the only choices are to use an encoder with a mask or have special encoders custom made. Obviously, the latter approach is practical only in high volumes.

Code wheels have improved as well. While many still consist of etched metal, Mylar, or emulsion on glass, these technologies are giving way to chrome on glass. Chrome on glass gives superior edge definition, greater immunity to condensation, and better durability. Superior edge definition also allows the code wheels themselves to be smaller.

Magnetic sensing

Magnetic sensors detect moving ferrous metal. The simplest magnetic sensor consists of a wire coiled around a permanent magnet. A ferrous object approaching the sensor changes magnetic flux through the coil, generating a voltage at the coil terminals.

Magnetic pickups require no external power source and sense linear or ro-

Product Spotlight

New and Expanded Products

EOMZ Series
Solid State Relays

W6/W9 Series
Circuit Breakers

T75 Series
P.C. Board Relays

RKS Series
P.C. Board Relays

CNS/CNT Series
Time Delay Relays

Slim Line
Input/Output Modules

The following pages provide an overview of new items, expanded series and other key products in Potter & Brumfield's broad line of stock switching components. For more information on these, or other P&B products, contact an authorized P&B distributor or sales representative. Call toll-free 800-255-2550 for the name and telephone number of one near you.

Note: Product specifications and availability are subject to change without notice. When multiple ratings are listed for a product series, no individual rating may be exceeded by the combination of others. The specifications and/or agency recognitions noted do not necessarily apply to all models within a particular series.

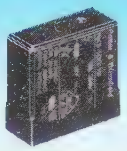
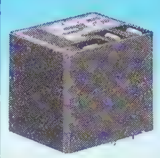
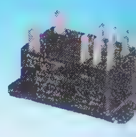
P&B's broad product line includes:

- ***Printed Circuit Board Relays***
- ***General Purpose Relays***
- ***Power Relays***
- ***Contactors***
- ***Latching & Impulse Relays***
- ***Reed Relays***
- ***Automotive Relays***
- ***Solid State Relays***
- ***Input/Output Modules***
- ***Time Delay Relays***
- ***Sensors***
- ***Circuit Breakers***

Potter & Brumfield A Siemens Company

Circle 390

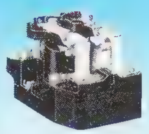
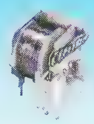
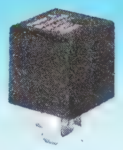
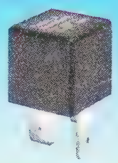
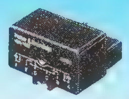
Printed Circuit Board Relays

			NEW PRODUCT	NEW FEATURES		NEW FEATURES	NEW PRODUC
							
Series	**T83**	**T70**	**T75**	**RKS**	**T90**	**T91**	**T92**
Features	- **2A rating** - Miniature, telecom relay - Meets FCC Part 68 isolation - Latching & non-latching - Sealed, immersion cleanable case - Sensitive coil types	- **10A rating** - Low cost - TV5 contact rating - 1,500 Vrms coil-to-contact breakdown - Immersion cleanable case	- **8 – 14A rating** - Meets international specifications - Sensitive coil - Low profile design - Immersion cleanable case	- **10 – 20A rating** - Meets international specifications - Meets 8mm spacing and 4kV isolation - Immersion cleanable case - AC and DC coils	- **30A rating** - Less than 1W coil power requirement - Class F coil insulation - Open, dust cover or immersion cleanable case	- **30A rating** - QC and PC terms. - Meets UL 873 and UL 508 spacings - Optional flanged case for panel mounting - Safety wells accept insulated female quick connects	- **30A rating** - Two pole unit ca break both sides the AC line - PC board or pan mount - Ideal for HVAC a appliance apps. - Designed to mee VDE requiremen
Approximate Dimensions	.80" x .40" x .42"h (20.2 x 10.2 x 10.7h) 0.18 oz. (5g)	.88" x .65" x .95"h (22.4 x 16.4 x 24.0h) 0.42 oz. (12g)	1.18" x .39" x .59"h (30 x 10 x 15h) 0.65 oz. (18.5g)	1.18" x .51" x 1.07"h (30 x 13 x 27.1h) 0.65 oz. (18.5g)	1.26" x 1.07" x .81"h (32 x 27 x 20h) 0.9 oz. (26g)	1.27" x 1.07" x 1.10"h (32.1 x 27.2 x 27.9h) 1.0 oz. (28g)	2.03" x 1.33" x 1.2 (51.6 x 33.8 x 30.5 2.95 oz. (84.3g)
Contact Arrangements	2 Form C	1 Form C	1 Form C	1 Form A, 2 Form A, 1 Form C, 2 Form C	1 Form A, 1 Form C	1 Form A, 1 Form B, 1 Form C	1 Form A, 1 Form C
Contact Material	Au overlay, Ag & PdAg	Au flashed Ag AgCdO	AgCdO	AgCdO	Ag AgCdO	Ag AgCdO	AgCdO
Maximum Contact Rating	2A, AC or DC 250VDC, 220VAC 50-150W or 250VA, resistive	10A @ 28VDC or 120VAC 5A tungsten @ 120VAC (AgCdO) 1/4 HP @ 120 VAC	14A @ 120VAC, resistive 10A @ 240 VAC 8A @ 24VDC	20A @ 24VDC or 277VAC 10A @ 30VDC or 277VAC UL TV-3 and TV-5	30A @ 240VAC 20A @ 28VDC 6A @ 277VAC, ballast 2 HP @ 240VAC UL TV-5 (Form A)	30A @ 28VDC or 240VAC 6A @ 277VAC 2 HP @ 240VAC T91E: 20A @ 75VDC	30A @ 277VAC 20A @ 28VDC TV10 @ 120VAC 2.5HP @ 240VAC 1HP @ 120VAC
Expected Mechanical Life	2 x 10^7 Ops.	1 x 10^7 Ops.	2 x 10^7 Ops.	1 x 10^6 Ops.	1 x 10^7 Ops.	1 x 107 Ops.	5 x 106 Ops.
Expected Electrical Life at Rated Load	3 x 10^5 @ 1.5A, 24VDC 1 x 10^5 @ 1A, 120VAC	7.5 x 10^4 @ 10A, 28VDC or 120VAC 5 x 10^4 @ 10A, 28VDC or 120VAC (Ag)	5 x 10^4 @ 14A, 240VAC 1 x 10^5 @ 8A, 240VAC	1 x 10^5 @ 10 A, 30VDC or 277VAC 2 x 10^4 @ 20 A, 277VAC or 24VDC	1 x 10^5 @ 30 A, 240VAC (Form A)	1 x 105	1x 105 Ops.
Nominal Coil Voltage	5-48VDC	5-48VDC	3-48VDC	5-48VDC 12-240VAC	5-110VDC	5-110VDC 12-240VAC	5-110VDC 24-277VAC
Nominal Coil Power	75-400mW	360mW	230mW	(DC) 520mW (AC) 1.6VA	870-930mW	870mW-1.5W (DC) 2.0VA (AC)	1.7W (DC) 4.0VA (AC)
Mounting Options	PC board, Socket	PC board	PC board	PC board	PC board	PC board, Panel mount	PC board, Panel mount
Sockets / Connectors	Fits 16-pin IC socket	—	—	—	—	—	—

Call toll-free 800-255-2550 for the name and telephone number of your nearby P&B sales representative or authorized distribu

Potter & Brumfield **A Siemens Company**
200 S. Richland Creek Drive, Princeton, IN 47671-0001 Fax: 812-386-2335

Circle 390

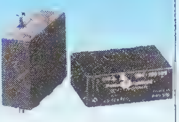
eneral Purpose Relays			Power Relay	Automotive Relays			
					NEW FEATURES		*NEW PRODUCT*
							
KH/KHA	**K10**	**KUP**	**PRD**	**VKP**	**VF4**	**VF7**	**VBA**
– 5A rating lew, automated esign (KHA) ompact package PDT switching Many mounting tyles Opt. indicator lamp Hermetically sealed ase option ЯU ⓈⓅ	• 15A rating • Compact package • DPDT switching • Various mounting configurations • AC and DC coils available ЯU ⓈⓅ	• 10A rating • Plain or bracket mount dust covers • Optional indicator lamp and push-to-test button • Various socket styles ЯU ⓈⓅ Ⓢ	• 30A rating • High inrush capacity • Magnetic blowout available to aid arc quenching when switching high voltage DC • Optional auxiliary switch ЯU ⓈⓅ	• 40A rating • Open frame relay for PC board mounting • Various contact arrangements	• 40A rating • Plug-in or PC board mountable relay • Several enclosure options • Various contact arrangements • Optional mounting brackets	• 70A rating • Plug-in or PC board mountable relay • 1 Form A contact arrangement • Optional mounting bracket	• 20A rating • Motor reversing relay module • Plug-in connections • Various mounting options
1" x .86" x 1.28"h .2 x 21.8 x 32.5h) 1.6 oz. (45g)	1.11" x .86" x 1.38"h (28.2 x 21.8 x 34.9h) 1.8 oz. (51g)	1.53" x 1.41" x 1.91"h (38.9 x 35.7 x 48.4h) 3 oz. (85g)	3.39" x 2.66" x 2.72"h (86.2 x 67.5 x 69.1h) 10 oz. (284g)	.911" x .748" x .715"h (23.1 x 19.0 x 18.2h) 0.7 oz. (20g)	1.12" x 1.12" x .987"h (28.5 x 28.5 x 25.1h) 1.1 oz. (31g)	1.03" x 1.03" x .992"h (26.2 x 26.2 x 25.2h) 1.1 oz. (31g)	1.01" x 2.02" x 1.91"h (25.6 x 51.3 x 48.5h) 2.5 oz. (70g)
2 Form C, 4 Form C	2 Form C	1 Form C to 4 Form C	1 Form A to 2 Form C	1 Form A, 1 Form C	1 Form A, 1 Form C	1 Form A	Motor reversing arrangement
, AgCdO, AuAgNi, Au overlay Ag, Au diffused Ag	AgCdO	Ag AgCdO	Ag AgCdO	AgNi 0.15	AgNi 0.15	AgNi 0.15	AgNi 0.15
Dry circuit to 5A 28VDC or 120VAC 1/10HP @ 120-240VAC	15A @ 30VDC or 120VAC 1/3HP @ 120VAC 1/2HP @ 250VAC	10A @ 28VDC or 240VAC 1/3HP @ 120VAC 1/2HP @ 250-600VAC	30A @ 277VAC 20A @ 125VDC 1.5HP @ 120VAC 2HP @ 250VAC	40A @ 14VDC	40A @ 14VDC	70A @ 14VDC	20A @ 14VDC
1 x 10^7 Ops.	1 x 10^7 Ops.	1 x 10^7 Ops.	2 x 10^6 Ops.	1 x 10^7 Ops.	1 x 10^7 Ops.	1 x 10^7 Ops.	1 x 10^7 Ops.
1 x 10^5	1 x 10^5	1 x 10^5	1 x 10^5	1 x 10^5	1 x 10^5	1 x 10^5	1 x 10^5
6-110VDC 6-120VAC	6-110VDC 6-120VAC	6-110VDC 6-240VAC	12-110VDC 12-480VAC	12VDC	12 & 24VDC	12VDC	12VDC
900mW (DC) 1.2VA (AC)	900mW (DC) 1.2VA (AC)	1.2-1.8W (DC) 2.0-2.7VA (AC)	2.0W (DC) 9.8VA (AC)	1.6W	1.6W	2.0W	1.81W
Socket, PC board	Socket, Panel mount, PC board	Socket, Panel mount, PC board	Panel mount	PC board	PC board, Plug-in, Bracket	PC board, Plug-in, Bracket	Spring-clip, Push-in fastener
Screw terminal, Solder terminal, PC terminal	Screw terminal, Solder terminal, PC terminal	Screw terminal, Solder terminal, PC terminal, Quick connect terminal	—	—	PC terminal socket, Wiring harness style connector with or without bracket	Wiring harness style connector	Wiring harness style connector

ll toll-free 800-255-2550 for the name and telephone number of your nearby P&B sales representative or authorized distributor.

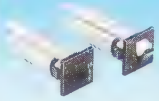
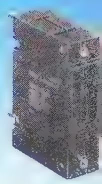
otter & Brumfield **A Siemens Company**
S. Richland Creek Drive, Princeton, IN 47671-0001 Fax: 812-386-2335

Circle 390

Time Delay Relays

	NEW PRODUCT 	*NEW PRODUCT* 	*NEW PRODUCT* 
Series	**CNT**	**CNS**	**OAT/ODT**
Features	• **10A rating** • Programmable timer/counter • Digital display • Universal input • 1/16 DIN style enclosure • Counts to 99,900	• **10A rating** • Programmable time delay relay • Universal input voltage • 1/16 DIN style enclosure	• **1A rating** • Solid state time delay relay/output module • AC and DC output • Universal DC input • Industry standard package
Approximate Size and Weight	1.88" x 1.88" x 2.83"h (47.8 x 47.8 x 71.9h) 4.3 oz. (122g)	1.88" x 1.88" x 2.83"h (47.8 x 47.8 x 71.9h) 4.3 oz. (122g)	.6" x 1.7" x 1.25"h (15.2 x 43.2 x 31.8h) 1.25 oz. (35g)
Contact Arrang.	2 Form C	2 Form C	1 Form A
Contact Rating	10A @ 30VDC or 277VAC	10A @ 30VDC or 277VAC	1A @ 60VDC (ODT) 1A @ 240VAC (OAT)
Mode of Operation	Programmable: Delay on Operate, Delay on Release, Interval On, Control-Off Interval On, Recycle, Single Cycle, Control On-Off Interval On, Control On-Off Delay, Pulse, Cumulative Delay on Operate, Operate at Set Count, Release at Set Count	Programmable: 8- and 11-pin types: Delay on Operate, Interval On, Recycle Initially On, Recycle Initially Off 11-pin types only: Delay on Release, Inverted Delay on Release, Switch Controlled Interval On, Interval Off	Delay on Operate Interval On
Delay Time	0.1 sec. to 9,990 hr.	0.1 sec. to 100 min.	0.1 sec. to 50 min.
Type of Control	Thumbwheel switches	DIP switches & Potentiometer Adj.	Potentiometer adj.
Maximum Repeatability	±0.1% ± 0.05 sec.	±0.2%	±0.3% (AC) ±0.1% (DC)
Max. Delta Time	±0.1% ± 0.05 sec.	±10%	±3%
Tolerance	±0.1% ± 0.05 sec.	Min. specified delay time or less at Min.; -0, +20% at max.	Min. specified delay time or less at min.; -0, +50% at max.
Temp. Range	-10°C to +55°C	-10°C to +55°C	-10°C to +70°C
Input Voltage	12VDC 24-240VAC/VDC	24-240VAC/VDC	3.5-25.6VDC
Mounting	Plug-in	Plug-in	Mounting board, PC board

Circuit Breakers

		*NEW FEATURES* 	*NEW FEATU* 
Series	**W28**	**W6**	**W9**
Type	Thermal	Magnetic	Magnetic
Features	• **Ratings to 15A** • Replaces slow blow glass cartridge fuse and holder • Labor-saving snap-in mounting • Button extends for visible trip indication • Push-to-reset operation	• **Ratings to 50A** • Compact design • Variety of time delay options • Toggle actuation for manual on/off and reset • Optional aux. switch • Meets VDE req'ments	• **Ratings to 50** • Variety of time delay options • Toggle actuat for manual or and reset • Optional aux. switch • Meets VDE req'ments
Approximate Size and Weight (per pole)	.54" x .63" x 1.54"d (13.7 x 15.9 x 39.0d) .35 oz. (10g)	.75" x 2.0" x 1.64"d (19.1 x 50.8 x 42.1d) 2.5 oz. (71g)	.75" x 2.5' x 2 (19.1 x 63.5 x 53 2.5 oz. (71g
No. of Poles	1	1, 2 or 3	1, 2 or 3
Circuit Function	Series Trip	Series Trip Series Trip w/ Aux. Switch	Series Trip Series Trip w/ Switch
Current Rating	0.25-15 Amps	1-50 Amps	1-50 Amps
Max. Operating Voltage	32VDC 250VAC	65VDC 277VAC 480VAC 3ø-Wye	65VDC 277VAC 480VAC 3ø-W
Trip Time at 200% of Rating	0.25-2A Models – 4.5 to 28 Sec. 3-15A Models – 2.2 to 15 Sec	30ms to 100 Sec. depending upon trip curve selected	30ms to 100 S depending upon curve selecte
Interrupt Capacity	1,000A @ 32VDC or 250VAC	1-20A Models – 2,000A @ 65VDC 5,000A @ 277VAC or 480VAC 3ø-Wye 21-50A Models – 2,000A @ 65VDC 2,500A @ 277VAC	2,000A @ 65V 5,000A @ 277V 5,000A @ 480VAC 3ø-W
Terminal Options	.250" (6.35) Quick Connect (Do not solder)	.250" (6.35) Quick Connect. #10-32 Screw	#10-32 Stu
Mounting	Snaps into 5/8" (15.9) panel cutout from the front	#6–32 Tapped Holes	#6–32 Tapped I

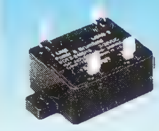
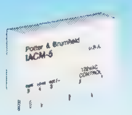
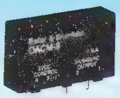
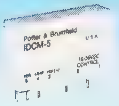
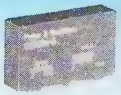
Call toll-free 800-255-2550 for the name and telephone number of your nearby P&B sales representative or authorized distrib

Potter & Brumfield A Siemens Company

200 S. Richland Creek Drive, Princeton, IN 47671-0001 Fax: 812-386-2335

Circle 390

Solid State Relays & Input/Output Modules

	NEW FEATURES 	NEW FEATURES 	NEW FEATURES 	NEW FEATURES 	NEW FEATURES 
Series	**EOMZ/TZ**	**IACM**	**OACM**	**IDCM**	**ODCM**
Features	• **25A rating** • Economically priced • Low profile, plastic base package • Triac output • DC input	• **0.1A output rating** • Slim line AC input module • Only 0.37" (9.4 mm) wide package • Series operation compatible	• **6A output rating** • Slim line AC output module • Only 0.37" (9.4 mm) wide package • Series operation compatible	• **0.1A output rating** • Slim line DC input module • Only 0.37" (9.4 mm) wide package • Series operation compatible	• **5A output rating** • Slim line DC output module • Only 0.37" (9.4 mm) wide package • Series operation compatible
Approximate Size and Weight	1.81" x 1.50" x .66"h (46.0 x 38.1 x16.8h) 2.3 oz. (65g)	1.7" x .37" x 1.0"h (43.2 x 9.4 x 25.4h) 0.9 oz. (25.5g)	1.7" x .37" x 1.0"h (43.2 x 9.4 x 25.4h) 0.9 oz. (25.5g)	1.7" x .60" x 1.25"h (43.2 x 15.2 x 31.8h) 0.9 oz. (25.5g)	1.7" x .60" x 1.25"h (43.2 x 15.2 x 31.8h) 0.9 oz. (25.5g)
Switch Arrangement	1 Form A	1 Form A (sinking)	1 Form A	1 Form A (sinking)	1 Form A
Coupling	Optical	Optical	Optical	Optical	Optical
nput	3-32VDC	10-36VAC/VDC 90-140VAC/VDC 180-280VAC/VDC	5VDC 15VDC 24VDC	4-16VDC 10-36VDC 18-60VDC	5VDC 15VDC 24VDC
Output Switching	Zero, Random	–	Zero, Random	–	–
Minimum Output Current	.02A	–	.02A to .05A	–	.02A
Maximum Output Current	25A	0.1A	6A	0.1A	5A
Minimum Output Voltage	20V	–	12V	–	5V, 10V
Maximum Output Voltage	280V	30V	280V	30V	200V
utput Type	AC	DC	AC	DC	DC
erminals	Quick connect, Screw	Printed circuit	Printed circuit	Printed circuit	Printed circuit
ounting	Chassis mount	Mounting board, PC board	Mounting board, PC board	Mounting board, PC board	Mounting board, PC board

Want to know more about P&B Products?

Additional details on the products described here, as well as other stock P&B products, can be found in the Potter & Brumfield Stock Catalog. Ask your P&B sales representative or authorized stocking distributor for a free copy. To learn the name and telephone number of a sales representative or authorized distributor serving your area, call toll-free:

800-255-2550.

Potter & Brumfield A Siemens Company
200 S. Richland Creek Drive, Princeton, IN 47671-0001 Fax: 812-386-2335

Circle 390

tary motion. They have high resolution, generating many pulses/in. of target travel, and can sense very small ferrous objects. For example, one sensor responds to 96-pitch gears, whereas Hall-effect sensors can only register 16-pitch gear teeth. In this application, magnetic transduction can be accurate to hundredths of a mechanical degree. For sensing rotating shaft speed, output-pulse frequency is converted to rpm by digital-conversion electronics at an accuracy of 0.1%.

Magnetic sensors have measured speeds up to 600,000 rpm. Maximum sensor frequency is in the megahertz region, with usable frequencies limited by the internal sensor impedance and external load.

Speeds near zero, however, cannot be measured because output voltage depends on the rate of change of flux through the coils. As frequency approaches zero, sensor outputs drop to the millivolt range.

The absence of electronic elements in a magnetic sensor allows operation beyond temperatures (−65 to 300°F) associated with solid-state devices. Magnetic sensors built with special materials operate at cyrogenic temperatures and withstand temperatures excursions greater than 400°F. Magnetic sensors are almost impervious to shock. Such devices have operated at shock levels exceeding 30,000 g.

Since magnetic sensors can detect ferrous discontinuities through nonferrous metals, they can be hermetically sealed within nonferrous housings to withstand 100% humidity or complete immersion in water and oil. Sensors enclosed in stainless steel can operate in salt spray or sand and dust environments, and under differential pressures up to 20,000 psi.

Eddy currents: Eddy-current sensors detect ferrous and nonferrous metals. A high-frequency magnetic field induces eddy currents in metal targets. The eddy currents generally change the sensor's oscillation amplitude, which is sensed by a coil to create an output signal. For measuring speed, these sensors register metallic discontinuities in a moving target at a rate of about 5 kHz, but some models respond up to about 20 kHz.

Maximum speed response is determined by the method used to sense oscillator amplitude. Devices that sense amplitude changes with conventional demodulator/integrator circuits are slower than those that convert oscillator amplitude into a string of pulses whose widths vary with frequency.

Eddy-current devices also produce pulses with high positional accuracy. Because eddy-current sensors do not depend on a time rate of change to register motion, their response does not diminish near zero speed like that of magnetic pickups.

Eddy-current devices are seldom contaminated by dirt or metal particles, but sensing distance is typically limited to the diameter of the sensor (usually 0.06 to 3 in.). These sensors must also be enclosed in nonmetallic packages because they cannot sense through metals.

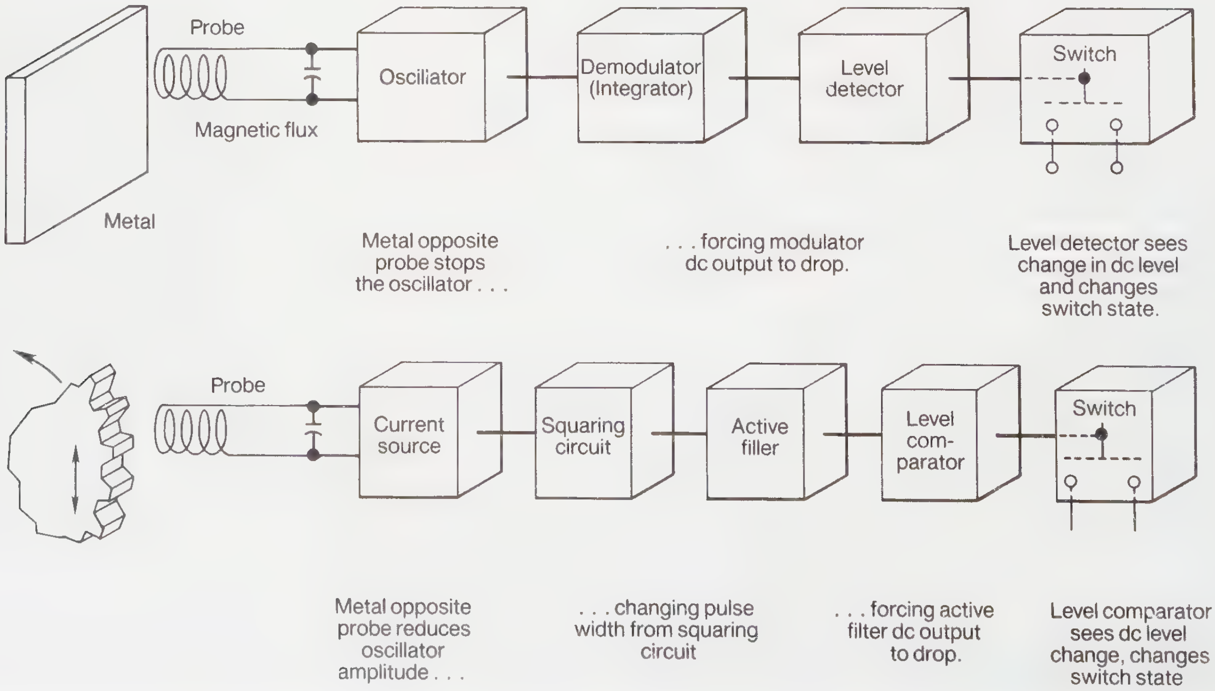
Other sensors

Many types of transducers are beneficiaries of IC technology. The benefits are twofold. There is the advantage of the chips themselves — enabling manufacturers to build more intelligence and better noise immunity into their transducers. However, it has become apparent that spin-offs from ICs have an equally important effect. For example, the same basic technology used to make the miniature circuits is helping to improve the resolution of optical encoders.

Especially impressive is how IC technology has helped reduce the cost of some devices. Just a decade ago, many pressure transducers cost $300 or more. Today, with the advent of micromachining, devices with similar capabilities may only cost a few dollars.

Temperature sensors: Temperature sensors include thermocouples, resistive temperature detectors (RTDs), and thermistors. Each device is limited

EDDY-CURRENT VELOCITY SENSORS


Probe
Oscilator
Demodulator (Integrator)
Level detector
Switch
Magnetic flux
Metal
Metal opposite probe stops the oscillator . . .
. . . forcing modulator dc output to drop.
Level detector sees change in dc level and changes switch state.
Probe
Current source
Squaring circuit
Active filler
Level com-parator
Switch
Metal opposite probe reduces oscillator amplitude . . .
. . . changing pulse width from squaring circuit
. . . forcing active filter dc output to drop.
Level comparator sees dc level change, changes switch state

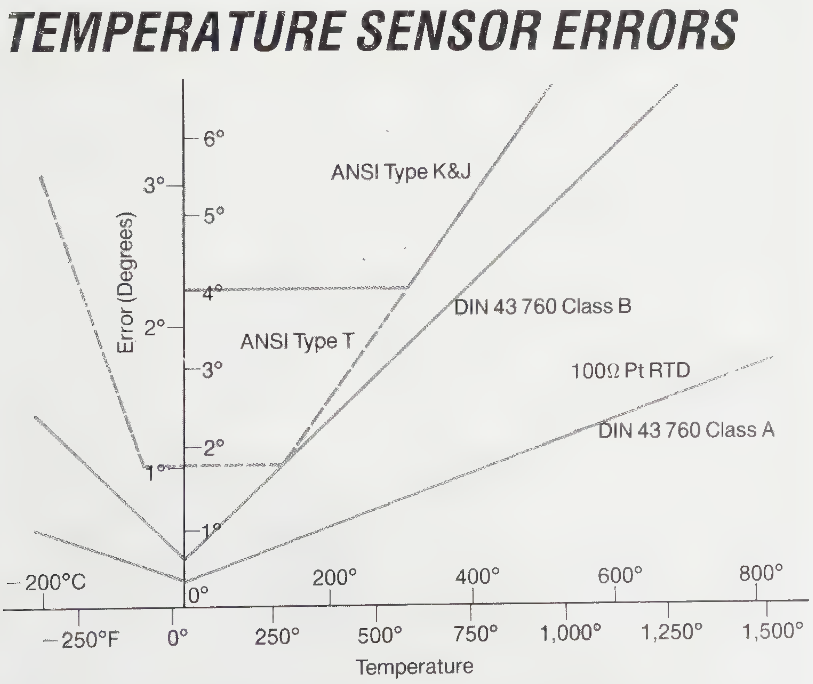
Comparison of various temperature sensors

	RTD						
Evaluation criteria	**100Ω Platinum wire wound and thin film**	**1,000 Ω Platinum thin film**	**1,000 Ω Nickel wire wound**	**2,000 Ω wire wound**	**Thermistor**	**Thermocouple**	**Semiconductor devices**
Cost — OEM quantity	High	Low	Medium	Medium	Low	Low	Low
Temperature range	Wide −400°F to +1200°F	Wide −320°F to +1000°F	Medium −350°F to +600°F	Short −100°F to +400°F	Short to medium −100°F to +500°F	Very wide −450°F to +4200°F	Short −57°F to 257°F
Interchangeability	Excellent	Excellent	Fair	Fair	Poor to fair	Good	Fair
Long term stability	Good	Good	Fair	Fair	Poor	Poor to fair	Good to fair
Accuracy	High	High	Medium	Low	Medium	Medium	Medium
Repeatability	Excellent	Excellent	Good	Fair	Fair to good	Poor to fair	Good
Sensitivity (output)	Medium	High	High	Very high	Very high	Low	High
Response	Medium	Medium to fast	Medium	Medium	Medium to fast	Medium to fast	Medium to fast
Linearity	Good	Good	Fair	Fair	Poor	Fair	Good
Self heating	Very low to low	Medium	Medium	Medium	High	N/A	Very low to low
Point (end) sensitive	Fair	Good	Poor	Poor	Good	Excellent	Good
Lead effect	Medium	Low	Low	Low	Very low	High	Low
Physical size/packaging	Medium to small	Small to large	Large	Large	Small to medium	Small to large	Small to medium

in terms of measurement accuracy. The amount of error associated with a given measurement approach must also be considered when choosing a sensor.

Thermocouples are widely used to measure temperature despite low sensitivity and moderate accuracy. They consist of two dissimilar metal wires joined at one end called the sensing junction. The voltage produced across this junction is proportional to its temperature. Because of a wide variety of usable wire materials, thermocouples collectively span an operating temperature range from −200 to 2,000 °C. Typical accuracies are from 1 to 3%, depending on material type and manufacturing variations. Sensitivities range from 40 to 80 μV/°C. Also, the response time for most thermocouples is on the order of a few seconds.

Connecting a thermocouple to a measuring device creates a second dissimilar-metal junction called the reference junction. In a type-J thermocouple, for example, the reference junction is formed where the iron lead connects to a copper terminal or wire. This junction is in series with the sensing junction. Voltage generated at the reference junction must be subtracted from the overall measured voltage to determine the temperature of the sensing junction.



Summarized in the graph are the standard limits of error for widely used thermocouples and platinum RTD temperature sensors.

To simplify temperature calculations, reference-junction temperature is maintained at a level that produces a known constant voltage. The most common reference is 0°C, which is the temperature of an ice bath. A 0°C reference insures repeatability and accuracy because the ice point of water is a constant. The National Institute of Standards and Technology accepts the ice point of water as the standard reference temperature.

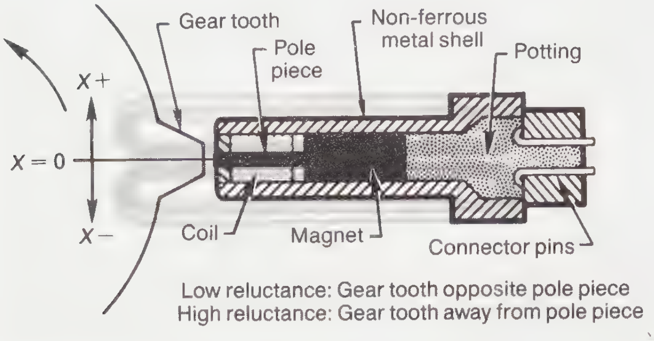
An ice bath may not always be convenient, however. In that case, the most common alternate method of determining reference voltage is with an integrated-circuit temperature sensor. The IC sensor is placed near the reference junction and measures local temperature. From its temperature reading, reference-junction voltage may be calculated.

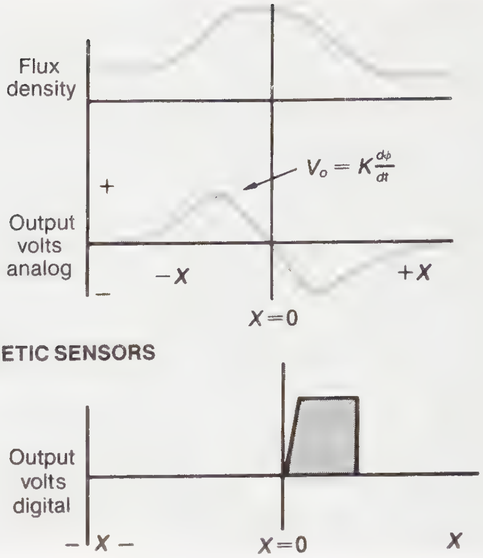
Thermocouples age or drift when used at high-temperature extremes. Aging is usually a much greater problem in the low-cost base-metal thermocouples than in those of platinum-based noble metal types.

The upper temperature limit of base-metal thermocouples in air is generally determined by their oxidation resistance. This limit varies with wire size. The type K thermocouple is the most widely used due to its oxidation resistance and high melting point. Even so, decalibration drifts of 10°C have been recorded with as little as 50 hr of exposure at 1,250°C.

A new nickel-base thermocouple called nicrosil/nisil has higher stability in air and better air-oxidation resistance at high temperatures than base-metal types. Its high-temperature drift

VELOCITY SENSING WITH MAGNETIC SENSORS


Gear tooth
Pole piece
Non-ferrous metal shell
Potting
X+
X = 0
X−
Coil
Magnet
Connector pins
Low reluctance: Gear tooth opposite pole piece
High reluctance: Gear tooth away from pole piece



is three times less than that of a type K device. Estimates are that maintenance costs for the new thermocouple are 12 times lower than those of type K.

Most materials change resistance with temperature variations. Two types of temperature transducers use this phenomenon: RTDs and thermistors. Depending on the measured temperature, these devices are increasingly used in lieu of thermocouples in many applications. The reason is simplicity. Thermocouples need special wires and cold-junction compensation; RTDs and thermistors do not. Thermistors find use up to about 100°C, while RTDs are practical up to about 400°C.

The primary difference between RTDs and thermistors is that the former use a metal-sensing element while the latter use a semiconductor. As a result, RTDs offer better linearity and are more stable at high temperatures. But RTDs usually cost more and require more complex measuring circuits.

RTDs typically consist of a wound platinum wire inside a glass or stainless-steel package. Platinum is preferred for several reasons. It is malleable, linear, has a higher resistivity than more common metals, and resists corrosion. While some low-cost RTDs use nickel alloy or copper wire, these sensors are usually less sensitive and have lower temperature ranges.

Wire-type industrial RTDs wrap the sensing wire around a bobbin. But for high-precision or laboratory measurements, the wire is left unsupported, a type of construction called a birdcage element. Because birdcage elements are free to expand or contract with temperature changes, they experience less strain. This, in turn, minimizes strain-induced resistance changes but makes the devices susceptible to failures caused by vibration.

While wire-wound bobbin RTDs are strong enough for most applications, a more rugged version is the thin-film type. Here, manufacturers screen a metal film (slurry) onto a ceramic substrate. The cured film is laser trimmed and sealed.

One problem with RTDs not made of platinum is a limited temperature range. For example, copper types can measure only up to about 120°C. To increase this limit, some manufacturers use permalloy (Ni-Fe), which has a resistivity several times greater than that of many other metals.

In picking temperature sensors, it is important to realize that packaging considerations limit RTDs to uses below about 400°C unless specifically designed for higher temperatures. The basic problem is iron poisoning of the platinum sensing element. At elevated temperatures, small amounts of iron impurities can leach out of the stainless-steel package and corrode the platinum. Two methods can prevent this. One is to use higher quality stainless-steel packages (324 or 327 alloys). The other solution is to place a quartz sheath between the detector and stainless-steel package.

Acquiring data from RTDs involves resistance measurements. Platinum RTDs start at 100 Ω at 0°C and vary by 0.0385 Ω for every 0.1°C change in temperature. Unfortunately, package leads made from copper wire also have a measurable temperature dependence. As temperatures increase, the resistance of the copper leads also increases. A lead resistance variation of as little as 1 Ω may cause measurement errors of a few degrees.

To avoid errors caused by lead-resistance variations, several measurement schemes use more than two lead wires. In multiple-lead RTDs, a constant-current source excites the sensor through one pair of leads, while the voltage drop is read from a separate lead pair. Because extremely small currents are in the voltage measurement loop, resistive (IR) drops are negligible.

One type of multiple-lead RTD has three wires and is commonly interfaced to measurement systems through a bridge-completion circuit. However, several weaknesses are associated with this technique. In order to provide repeatable measurements, lead resistances must closely match, and the bridge must remain balanced. Although a potentiometer may be used to balance the bridge, it also causes major inconveniences. For one, the electromechanical device is unstable over time and requires frequent adjustment. Also, an adjustment is necessary every time the RTD is replaced.

A four-wire ohms-measurement circuit is a better method to cancel the effect of lead resistance. A stable power supply forces a known current through the RTD and the primary lead resistances. Because the input impedance of the measuring circuit is usually greater than 10MΩ, virtually no current flows, and no voltage is dropped across voltage sense leads. The resistance of the RTD is found by dividing measured voltage by source current.

Thermistors, like RTDs, are temperature-sensitive resistors. As temperature increases, thermistor resistance decreases, but at a much faster rate than that of RTDs. As a result, thermistors can sense minute changes in temperature that are otherwise undetected by RTDs and thermocouples.

Temperature coefficients for thermistors are typically as large as −2 to

These sensors are identical. Why is one doomed from the start?

Because it didn't fit the application, a perfectly good sensor could become unreliable.

What Really Makes a Sensor Reliable?

Over fifty years experience in industrial presence and position sensing has taught us that sensor reliability is a function of both sensing *technology* and proper *application*.

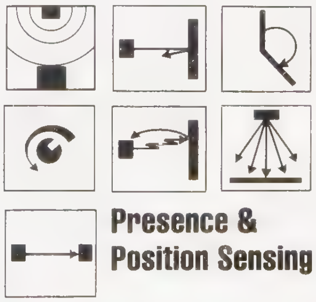
The key to the proper application of today's sensor is the availability and reliability of application data and support services from your vendor.

Ultimate Reliability: Benefit From What History Has Taught Us

Working as your partner, Namco will match the proper sensing solution to your requirements. If one of our standard products will not perform properly in your environment, many times we'll develop a new one that will. Time and again, this close communication has guaranteed ultimate reliability for our customers. All of our fully encapsulated, solid state proximity and photoelectric sensors are eligible for our lifetime replacement program.

Challenge Us With Your Application

Call Namco now to have us match the proper sensing technology to your need.


Presence & Position Sensing

Free Brochure *matches Namco sensing technologies to specific industry solutions. Proximity and photoelectric sensors as well as electronic cam boxes, radio frequency identification and laser sensors are included.*

NAMCO

Namco Controls
An Acme-Cleveland Company
7567 Tyler Blvd., Mentor, OH 44060
1-800-626-8324; in Ohio, 216-946-9900
Fax: 216-946-1228

Circle 393

−6%/°C, compared to about 0.4%/°C for RTDs. Most thermistors have a resistance of 5,000 Ω at 25°C and sensitivities between 100 and 300Ω/°C, much larger than the 0.4-Ω/°C sensitivity for 100-Ω RTDs. Bridge-completion and ohms-measurement circuits are not needed when connecting thermistors to acquisition equipment because lead resistances are negligible with respect to sensor variations.

An average thermistor with a temperature coefficient of 4%/°C for example, changes 200Ω/°C. At this level of sensitivity, a measurement lead with a resistance of 10 Ω only contributes a 0.05°C error. The same lead causes an error of 25°C in a 100-Ω RTD, 500 times worse.

Compared to other sensors, thermistors have a limited measuring range, typically from −80 to 150°C. Also, because they are often made from semiconductors or sintered mixtures of metal oxides, they can sustain permanent damage at temperatures above their specified operating range.

Another problem is called self-heating error. As thermistors dissipate power they may warm slightly. Because they are so small, typical power dissipation constants are about 1mW/°C. When measuring cold temperatures, for example, it is possible for the device to be warmer than the temperature being measured. Thermistors also are more nonlinear and curve-fitting polynomial equations or resistance-temperature lookup tables are often used to approximate temperature.

A significant advantage of thermistors, however, is that they easily interface with PCs, requiring very little circuitry. In many cases a simple voltage-divider network is sufficient. A dc supply produces a voltage V_s that is shared between the thermistor and the fixed resistor R. The voltage V_o across the fixed resistor is measured to calculate thermistor resistance R_T.

The best value for the fixed resistor is determined from several temperature curves. The resistor value is chosen based on the specified thermistor, resistance ratio, temperature range, and required linearity. Most thermistor manufactures provide literature that simplifies the complicated process.

Manufacturers sometimes place thermistors in two groups determined by lead attachment. The first classification is the bead type. These have platinum wires sintered into a ceramic body (bead). Beads are sometimes left bare or have an organic coating (epoxy), but those sealed in glass have the best stability (temperature drift over time). Stability is directly proportional to glass thickness because the thicker glass helps prevent changes caused by oxidation. For instance, a bare bead drifts ten times more than a glass-coated one.

Metallized surface-contact thermistors form the second group. These are called chips or flakes. In contrast to bead types, leads are not sintered directly into the ceramic. Instead, the sintered ceramic is coated with a metallic contact. Either the chip manufacturer or user attaches leads to this contact.

One advantage of chip thermistors over bead types is that the chips are easily trimmed by cutting or grinding. Thus, they are easy to match and, therefore, are interchangeable. While matched bead thermistors are available, they cost more than interchangeable chips.

Interchangeability is one of the major advantages of thermistors. The 2,252 Ω elements have a unit-to-unit variation of less than ±0.2°C from 0° to 70°C. Decalibration drifts are on the order of less than 1°C per year if used constantly at 150°C. Drifts of less than 0.3°C can be expected at temperatures below 100°C.

Temperature switches: These devices typically comprise sensing elements and switching contacts housed in a single mechanical assembly. The sensing element measures temperature and actuates the contacts in response to thermal variations. Switches may open or close on temperature rise depending on their internal construction.

In most applications, temperature switches provide one of two functions: control or cutoff. Temperature switches operating in the control mode are called thermostats. They are used to maintain the temperature of a system within a specified range. Their contacts either pass or block control

SPECIFYING THERMOSTATS

Thermostats are specified based on several operating factors. The major ones are operating temperature range, tolerance or resolution sensitivity, operating differential, speed of response, and cycle life. Each is determined by the thermostat's mechanical design, construction materials, and sensing elements.

Temperature range is the overall safe operating range of the device. Expected temperatures in a controlled system should fall well within the thermostat's operating range, allowing some room for overshoot or undershoot.

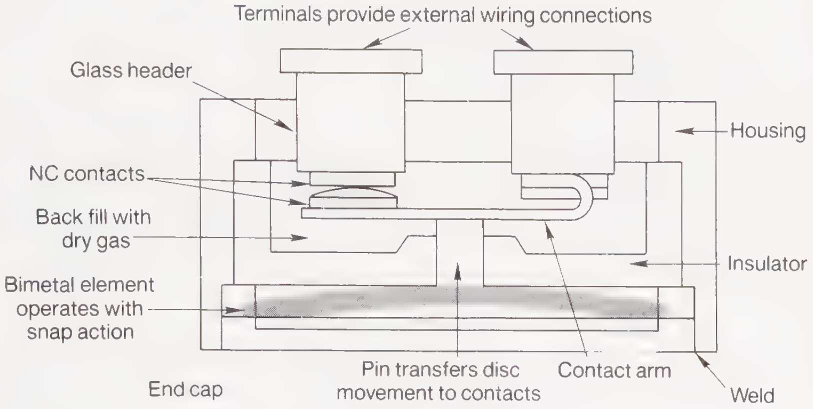
Tolerance is a measure of switching accuracy. Expressed in degrees, it is the maximum error in make or break temperature. A thermostat with a tolerance of 3°F, for instance, and a specified make or break temperature of 120°F, may switch from 117 to 123°F.

A related figure of merit, **resolution sensitivity**, is the amount of temperature change needed to actuate the contacts. Consider a temperature switch that has a 5°F resolution sensitivity and a make or break point at 80°F. If the steady-state temperature is 78°F, the thermostat will not switch until it senses at least 83°F. Of course, the specified switching point is also subject to a certain tolerance.

A thermostat's **operating differential** is defined as the difference between make and break temperatures at the sensing element. Narrower operating differentials provide tighter control of the system temperature. But a differential that is too narrow will not allow the controlled system adequate time to cool down. Because more heat is delivered into the system than expended, temperatures will rise to an unsafe level. Another benefit of a wider differential is that contacts switch less frequently, increasing thermostat service life.

Speed of response is the elapsed time from the instant a make or break temperature occurs at the sensing element until it is converted into switch actuation. Speed of response is affected by the mass, thermal conductivity, and location of the sensing element. In general, thermostats whose sensing elements are on the exterior of the package will respond faster. Also, low-mass sensing elements typically react faster than larger elements.

Temperature-switch **cycle life** is specified in terms of actuation cycles. Conditions that reduce cycle life include excessive overtemperature, above-rated electrical loads, and in some thermostat types, severe shock and vibration. Minimum required cycle life for many electrical products is dictated by safety codes. Typical requirements are 6,000 cycles for manual reset switches, 30,000 for thermostat controls, and 100,000 for limit switch or cutoff applications.


Terminals provide external wiring connections
Glass header
Housing
NC contacts
Back fill with dry gas
Insulator
Bimetal element operates with snap action
Pin transfers disc movement to contacts
Contact arm
End cap
Weld

BIMETAL-DISC SNAP-ACTION THERMOSTAT

In snap-acting bimetallic-disc temperature switches, motion of the disc is transferred to the contact through a pin. Both NC and NO configurations are available. Upon actuation, the disc snaps quickly and pulls the contacts apart, sometimes in less that 0.1 ms.

currents as a function of system temperature as measured.

In the cutoff mode, temperature switches protect equipment against over or undertemperature conditions. In many cases, temperature cutoffs are a backup for a primary temperature controller. Once temperatures return to normal, some cutoffs automatically reset, while others must be manually reset. One type of cutoff, called thermal fuse, must be physically replaced following actuation.

Electromechanical temperature-actuated switches are available in several different forms. Designers can choose from reed switches, liquid-filled thermostats, mercury-in-glass tubes, and a family of differential-expansion devices.

Differential-expansion thermostats are the most common ones used today. They operate on various switching mechanisms including bimetallic discs, fused-bimetal elements, and mechanically linked assemblies. Some switch with a snapping action, while others, called creep-type switches, change states gradually.

Differential-expansion thermostats make use of an interaction between two metals with widely varying coefficients of thermal expansion. The interaction causes a movement that actuates a set of contacts, opening or closing them.

One type of differential-expansion switch is the **fused bimetal** thermostat. In bimetal thermostats, the sensor is made of two strips of dissimilar metal bonded into one element. When the temperature changes, unequal expansion of the two metals causes the strip to bend into an arc. The movement either makes or breaks an electrical contact.

In some cases, the bimetal element is the current-carrying conductor, while in others it only pushes the conductors together. In either case, the movement of the bimetal strip is gradual, and the amount of movement is proportional to the temperature. The make temperature is calibrated with an adjusting screw that varies the position of the fixed contact.

Fused-bimetal thermostats are typically used in electric blankets. Normally closed contacts pass current, allowing the blanket to heat. Electric blankets remain at a safe operating temperature with full heating current applied. If an overtemperature occurs, the bimetal strip deflects and breaks the circuit. When the cause of overheating is removed, the switch returns to a normal state.

A potential problem with fused-bimetal thermostats is contact arcing. Because the contacts slowly open and close, arcing may occur during intermediate states where contacts are close together or only lightly touching. Arcing wears out the mating surfaces of the contacts and raises contact resistance. As a result, cycle-life limits of creep-type fused-bimetal thermostats should be closely observed, especially in products where many actuations are expected.

In contrast, **snap-acting bimetal** thermostats open and close extremely fast with greatly reduced arcing. Switching times are as low as 0.1 ms. Rapid-contact separation insures long contact life as well as calibration stability. It also reduces the amount of radio-frequency interference that moving contacts often generate.

Most snap-acting elements are concave bimetal discs. When the temperature changes, expansion on one side is much greater than that on the other. The stress created by the unequal expansion increases until it overcomes the biasing stress. At that point, the disc inverts with a snap into a convex shape. When normal temperatures return, the process is reversed.

Bimetal-disc thermostats usually have a fixed (tamperproof) temperature setting and a relatively large operating differential. The large differential makes them useful when a substantial dead zone (10 to 20°F) is desirable. Some bimetallic switch makers recommend a minimum differential of 15°F, and 25°F for systems operating above 250°F. This optimizes the trade-off between the operating differential and the crispness of the snap action. Switching elements with small operating differentials have reduced snap action.

Bimetal-disc thermostats respond to temperature changes down to about 3 or 4°F. They can sense airstream or surface temperatures and radiant heat. Their operating range is from −20 to 1,490°F. They can switch dry circuit loads of 400 Vac at up to 50 A.

Another type of differential-expansion thermostat is a **mechanically linked strut and shell.** Unlike bimetal switches where two metals are bonded together into a single element, the active metals in mechanically linked switches remain separate. The more thermally active metal, usually brass or stainless steel, is the switch housing or shell. The less active metal, usually a high-nickel alloy, is a strut assembly on which the contacts are mounted.

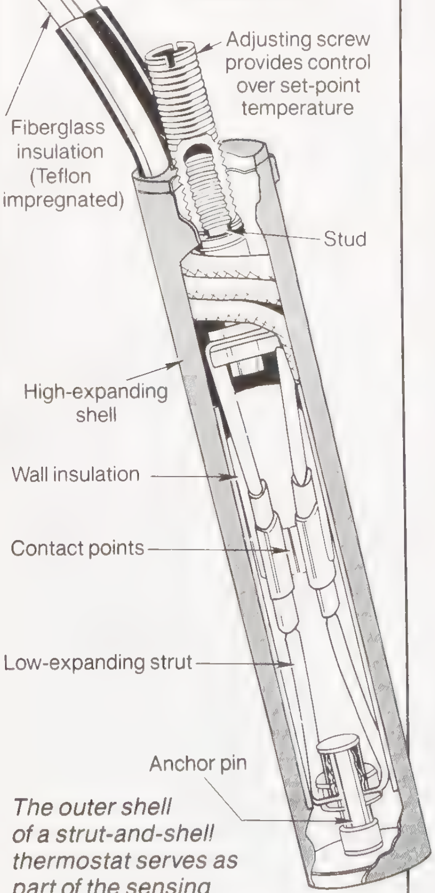
As temperatures vary, the shell and strut expand or contract unequally, opening or closing the contacts. Actuation temperatures are adjustable with a screw that either compresses or stretches the strut assembly. Because their outer shells are active sensing elements, strut-and-shell switches respond extremely fast to temperature changes.

One advantage of strut-and-shell thermostats is that they typically have high-resolution sensitivity, down to 0.1°F. Because the switching mechanism makes or breaks slowly (creep action), almost any temperature change causes a corresponding change in contact spacing. That is, contact action can be produced by very small temperature variations. In contrast, snap-acting bimetal elements often have resolution sensitivities of several degrees because a finite amount of energy must be absorbed to overcome the restraining forces holding the contacts in place.

Strut-and-shell thermostats also have high vibration and shock resistance. Because the strut assembly is constantly under tension or compression, it resists mechanical shock and vibration. This allows it to operate reliably and accurately under physically harsh conditions. Such hazards can cause problems in other types of differential-expansion switches.

Another advantage of the strut-and-shell switch is that it "anticipates" rapid temperature changes as a result of an inherent time lag between the shell and internal struts. The lag allows the shell to lead the struts by a time interval proportional to the rate of temperature change. In the case of rapid temperature change, the shell exerts a larger net force on the struts and actuates the switch sooner than for a gradual change. This produces several degrees or more of anticipation, leading to a tighter control band.

STRUT-AND-SHELL THERMOSTAT


Adjusting screw provides control over set-point temperature
Fiberglass insulation (Teflon impregnated)
Stud
High-expanding shell
Wall insulation
Contact points
Low-expanding strut
Anchor pin

The outer shell of a strut-and-shell thermostat serves as part of the sensing mechanism. Because the shell expands at a much higher rate than the inner struts, contact points may be forced together or pulled apart depending on the direction of the temperature change.

Another mechanically linked type operates on a stainless-steel **sensing tube**. The tube contains a two-section inner rod whose active section expands at a much lower rate than the tube. The expansion difference is multiplied by a lever that actuates a snap switch or pilot valve. Sensing-tube thermostats operate at up to 2,000°F.

Liquid-filled thermostats, although slower than differential-expansion types, typically handle more current because their switches are not part of the sensing system. As a result, a wide variety of interchangeable switches can provide various types of service including 20 A at 120 or 240 Vac, narrow differential, high inrush, and manual reset.

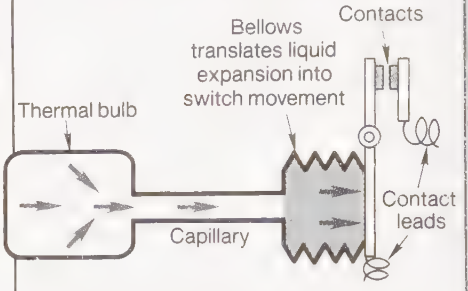
Liquid-filled thermostats employ temperature-sensing bulbs that contain an incompressible liquid. The type of liquid determines the operating range. As the temperature varies, the volume of the liquid expands or contracts. This displacement is transmitted hydraulically through a bellows or diaphragm. Bellows motion, in turn, can be transmitted through a push rod or other mechanical linkage to actuate the contacts of a dedicated electrical switch.

Both local and remote-temperature control is possible with liquid-filled switches. Local-bulb types enclose the sensing liquid, bellows, and push rod in a single shell. The electrical control switch is attached to the top of the shell.

Remote-temperature control is provided by a bulb-and-capillary arrangement. The metal bulb, filled with sensing fluid, is connected to the bellows and switch mechanism through a thin capillary tube about 6 to 10 ft long. The capillary transmits fluid expansion from the metal bulb to the bellows.

In contrast to differential-expansion thermostats, liquid-filled versions are less sensitive and considerably slower. Because of this, they respond to average temperature rather than instantaneous. Average temperature measurement is appropriate for applications with a large thermal time constant. For example, liquid-filled thermostats are suited for controlling temperatures in waterbed mattresses, commercial cooking ovens, and environmental chambers.

BULB-AND-CAPILLARY LIQUID-FILLED THERMOSTAT



Liquid-filled thermostats rely on the expansion of a liquid to actuate a pair of contacts. The volume of liquid increases or decreases with temperature change. This expansion is translated to the contacts by either a bellows or diaphragm. One advantage of bulb-and-capillary types is that the sensor and current-carrying contact can be separated from each other.

Bulb-and-capillary thermostats control remote switches, removed from the environment or process under control. Control switches, therefore, do not have to operate under the severe temperature conditions where the sensors are located. Also, because switches are not incorporated in the sensing element, liquid-filled bulbs can have a smooth tubular shape. Such a profile is mechanically strong and easy to design in a product. Under a waterbed mattress, for instance, the bulb withstands high forces and is not a puncture threat.

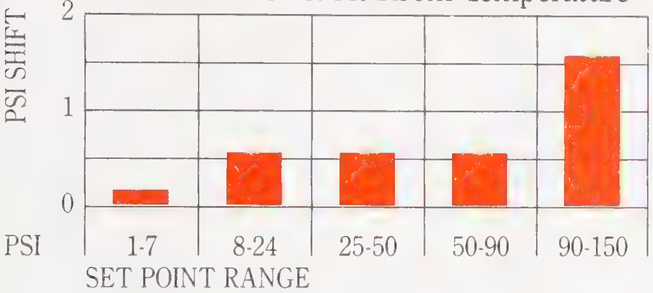
Mercury-in-glass thermostats are the most accurate of the electromechanical temperature switches. They provide resolution sensitivity and repeatability equal to that of RTDs and thermistors. Resolutions to ±0.05°F are possible. Temperature ranges extend from −40 to 550°F.

Their construciton consists of a mercury-filled bulb with an attached glass capillary tube. Two wires penetrate the capillary wall and act as a normally open contact. As temperature increases, the expanding mercury travels up the capillary tube until the two wires are shorted. The switching temperature is determined by the distance between the wires.

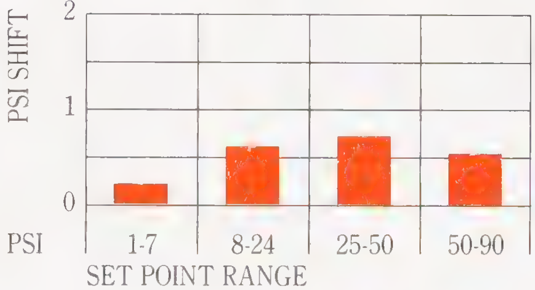
Advantages of mercury temperature switches include low cost, long lifetimes with a minimum of 1-million cycles, and limited drift less than 0.09°F. Also, they can switch with reduced arcing by the addition of an arc-suppressing gas. The most notable disadvantage, however, is a phenomenon called separation. Separation is a break in the

When it comes to maintaining set point, few other moderately priced switches come close to the Hobbs 5000 Series.

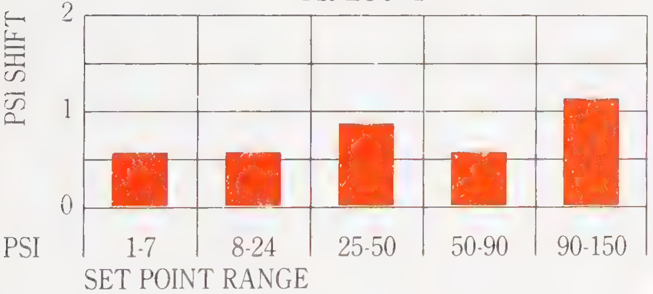
Calibration Shift At Room Temperature



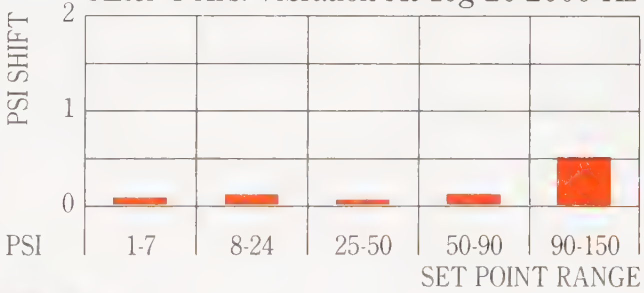
At −40°F



At 250°F



After 4 Hrs. Vibration At 10g 20-2000 Hz



The Hobbs 5000 Series pressure switch. It can be calibrated and sealed at the factory at a point as low as ½ PSI, as high as 150 PSI, with an operating pressure up to 250 PSI. And as the charts you see here indicate, tests over 500,000 cycles show that set point is maintained much better by the 5000 Series than most modestly priced switches. At room temperature, calibration shifts less than 2 PSI, even in the 90-150 set point range. At −40°F, less than 1 PSI over a range of 1-90 PSI. At 250°F, it barely drifts over 1 PSI across the set point range. And after prolonged vibration at 10g 20-2000Hz, shift is imperceptible except for a mere ½ PSI in the 90-150 set point range. No doubt about it, this is a switch that is ideal for extended duty applications. It is available with screw or blade terminals, and in a sealed connector version. The 5000 Series switch is also compatible with a wide variety of fluids, thanks to a polyimide film diaphragm. And last, but far from least, it is definitely priced right.

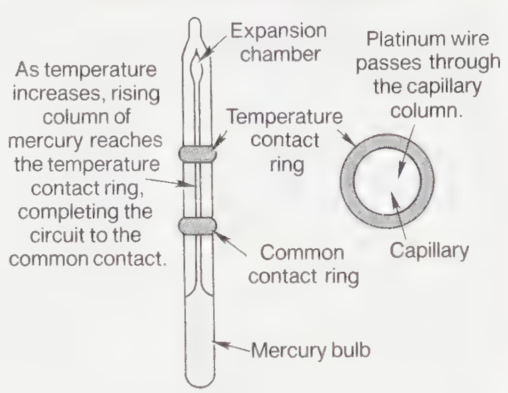
Hobbs. Tough Switches For Tough Customers.

Hobbs Corporation
P.O. Box 19424
Springfield, IL 62794-9424
Phone: 217-753-7791
Fax: 217-753-7789

Circle 394

Mercury-in-glass temperature switches are basically precision thermometers with two or more platinum wires that extend through the glass into the capillary passage. Mercury thermostats are available with adjustable set points as well as multiple-setting capability. One of the most accurate thermostats, they provide sensitivities down to 0.05°F.

MERCURY-IN-GLASS THERMOSTAT


As temperature increases, rising column of mercury reaches the temperature contact ring, completing the circuit to the common contact.
Expansion chamber
Platinum wire passes through the capillary column.
Temperature contact ring
Capillary
Common contact ring
Mercury bulb

mercury column caused by a sudden shock or extreme overtemperature. Although the condition is correctable, it typically requires human intervention.

Current ratings for mercury thermostats are typically between 10 and 25 mA at 115 Vac. As a result, additional control circuits are often needed to handle higher loads. Integrated solid-state relays provide up to 5 A of switching capability, with 1A being standard. A solid-state interface, such as a transistor or SCR, allows mercury thermostats to switch inductive or capacitive loads.

Mercury-in-glass thermostat makers, now offer miniaturized packages, some no larger than a penny. Also available are mercury thermostats with multiple set points, adjustable set points, and built-in solid-state relays.

Reed-switch temperature sensors work according to a simple principle of magnetics: at a critical temperature, called the Curie point, certain materials undergo a transition from being ferromagnetic to paramagnetic. That is, they go from a state of low reluctance to high reluctance (low permeability). This transformation actuates a set of contacts.

A temperature-sensitive reed switch is constructed with two toroidal magnets separated by a ferrite collar. Operating temperature is determined by the Curie point of the ferrite collar. The ferrite is a magnetic material produced by substituting iron atoms in a crystalline structure with nickel zinc, manganese zinc, and other materials. By varying the compositon of the ferrite, the Curie temperature can be adjusted over some range. One reed-switch maker offers sensors that operate from 14 to 482°C.

At temperatures below its Curie point, the collar shunts magnetic flux from the south pole of one magnet to the north pole of the other. Here, the stack behaves like a continuous magnetic tube. Flux lines are coupled from one end of the stack to the other through the reeds, holding them closed.

Above the Curie point, the permeability of the ferrite collar decreases, causing it to resist the passage of flux lines. At this point, the two magnets are no longer coupled and flux lines remain localized near the individual magnets. Because there is no magnetic field at the center of the stack, the reed contacts open.

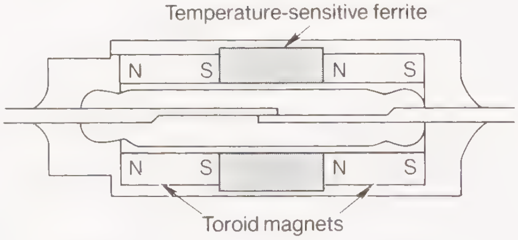
When designing with reed-switch thermostats, be aware of the magnetic-field environment of the application. Testing has shown that subjecting a reed switch to strong magnetic fields or enclosing one within a magnetic shunt — such as a ferrous-metal clamp — causes the apparent operating temperature to vary. However, the effects of common fields, such as those near motors or solenoids and mounts on sheet-metal enclosures and I-beams, usually are not severe.

Ferrous metal within the vicinity of a reed switch provides a low-reluctance shunt path that diverts some of the flux lines outside the package. This reduces the amount of flux within the package that otherwise holds the reeds together. For example, mounting reed switches directly on a ½-in. steel plate can cause trip temperature to drop by 4°C (7°F). Test data reveal that environmental effects can be minimized when sensors are mounted ⅛ in. or more away from flat ferromagnetic surfaces.

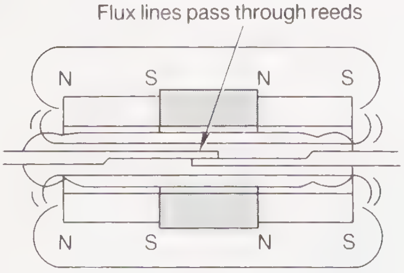
Innovations in product packaging are chiefly responsible for im-

A temperature-sensing reed switch is constructed with two permanent toroidal magnets separated by a ferrite collar. Enclosed within the tubelike cavity are a pair of reed contacts.

REED-SWITCH THERMOSTAT (FORM B)

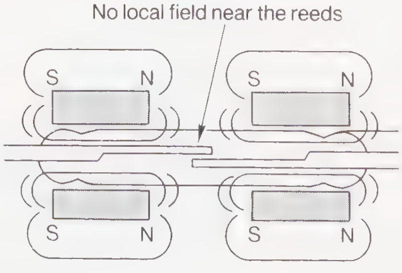


NORMAL TEMPERATURE — CLOSED CIRCUIT



Below the Curie temperature, the ferrite ring is highly permeable and shunts the magnetic field between the two permanent magnets. Inside the package, the flux loop is closed through the reeds, holding the contacts together.

OVERTEMPERATURE — OPEN CIRCUIT



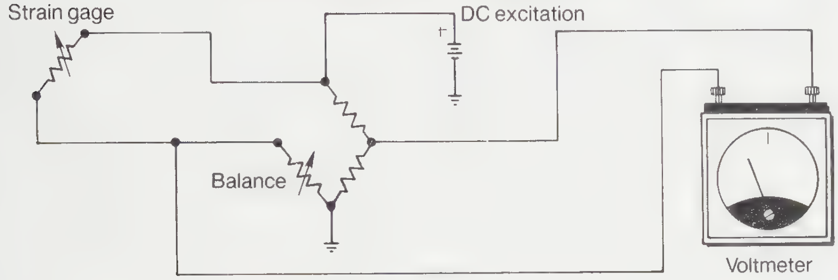
Above the Curie temperature, the ferrite ring is highly reluctant and blocks magnetic flux. Field lines from each magnet are closed both inside and outside the package, but no flux flows through the reeds. As a result, the contacts open.

provements in the mature temperature switch market. For example, one temperature switch maker recently announced a ¾-in. snap-acting bimetallic disc with an internal heating element that provides remote control of the operating temperature set point.

A biasing heater allows the single device to activate at any number of set points within a given range. By changing the voltage applied across the heater, varying amounts of supplemental heat is delivered to the bimetal element. Adding heat to the sensing element allows the device to switch at lower ambient temperatures.

Primary applications for the device include gas and electric clothes dryers. Here, the thermostat provides control over the temperature of the drum. One device allows dryers to have multiple setpoint temperatures corresponding to various fabric types.

STRAIN-GAGE WHEATSTONE BRIDGE



Strain-gage resistances are often measured with Wheatstone bridges powered by dc sources. A balancing resistance is used to null the output signal under no-load conditions. With the strain gage loaded, a change in sensor resistance causes the output voltage to vary. The amount of adjustment needed to rebalance the bridge is equal to the stress-induced variation in strain-gage resistance.

In conventional designs with multiple temperature settings, dryers typically contain three thermostats with nominal calibrations of 135, 145, and 155 ±5°F. Because the set points are so close, it is possible for two adjacent settings to operate at very near the same temperature.

Internally heated thermostats called Anticipators, instead of controlling operating temperature, anticipate temperature changes. This forecasting is possible when a fraction of the control current is diverted through the internal heating element. The advantages are reduced thermal overshoot in heating applications, and a tighter operating differential without sacrificing crisp snap action.

Other new thermostats have built-in tilt switches and pilot lights for indicating unsafe or dangerously high set points. Tilt switches protect against fire in the event electrical appliances or heaters are knocked over. Typical causes of upset include misuse, children, animals, and earthquakes.

Other improvements include miniature thermostats available in a wide variety of packaging styles. Bimetallic snap-acting temperature switches are now available in standard TO-220, and 8-pin DIP packages. Standard packaging allows the thermostats to be mounted on PC boards with automatic pick-and-place equipment. Nickel-plated copper mounting brackets provide good thermal contact to heat sinks or other thermally conductive surfaces.

Strain gages convert mechanical compression and elongation into electric signals. The most widely used strain gage for stress analysis is the bonded-resistive type. It is often chosen because of low cost, small size, insensitivity of temperature change, and high sensitivity to strain. Bonded-resistive strain gages can be as small as 16mm^2 and have a strain sensitivity or "gage factor" of 2.

Bonded-resistive strain gages produce a change in electrical resistance proportional to variations in strain. The sensor is made from a grid of very fine wire or a thin metallic foil bonded to a thin insulating backing called a carrier matrix. The carrier matrix attaches to test specimens with an adhesive. When the specimen is mechanically stressed (loaded), the strain on the surface is transmitted to the resistive grid through the adhesive and carrier layers.

The most widely used technique for reading strain gages is the Wheatstone bridge method because of its high sensitivity. The basic configuration, where the strain gage is one leg of the bridge, is called a quarter bridge. Other configurations include half and full-bridge networks.

When the specimen is strained or loaded, a change in sensor resistance causes a measurable variation in voltage. The amount of adjustment needed to rebalance the bridge is equal to the stress-induced variation in strain-gage resistance. The bridge is rebalanced when the output is nulled.

Most strain gages are supplied with a calibration factor typically expressed as a ratio of signal to excitation per full-scale pressure, mV/V/psi. For example, a strain gage may have a calibration factor of 30 mV/V/100 psi. The voltage difference measured by the Wheatstone bridge is applied to the calibration factor through software to determine the strain or load on the sensor and test specimen.

Full-scale load is normally specified within the calibration factor. Full-scale represents the maximum load that the sensor can withstand. Going beyond this value may cause inaccurate readings, and in some cases, damage the strain gage.

Pressure sensors are undergoing rapid change. Many foil or wire-bonded devices are giving way to silicon-based sensors. One reason is that silicon has excellent mechanical qualities that make it a good sensing element. For example, silicon has a higher elastic limit than steel in both tension and compression. And a single-crystal silicon diaphragm retains its original shape and dimensions even after being subjected to many pressure cycles. Steel, being a polycrystalline, tends to fatigue and break because of stress accumulation at intercrystal boundaries. Silicon also has a much higher gage factor than foil or wire-based devices.

Many types of pressure sensors are available from hundreds of different manufacturers. Not all meet the same service demands. There are vast differences between a bona fide hydraulic transducer and a volume-produced, low-cost sensor in the under $10 price range. Sorting through the possibilities to select the best transducer for a given application can be a formidable task.

Motion transducers use a bellows or Bourdon tube to convert pressure to an output. In one common type, the LVDT, an inductive member is driven into or out of a coil. It contains numerous pivots and linkages, making it nonlinear and susceptible to wear and vibration, but it has the advantage of inherently high output.

Pressure potentiometers have characteristics similar to those of

FIRE PREVENTION WITH TCOs

Motors, transformers, household appliances, and many other electrical products can be potential fire hazards. Fires are normally caused by a malfunction, where energy (electrical) flowing into the system is much greater than that flowing out (thermal, mechanical). In such a case, the best action is to turn off the power.

An easy way to protect electrical equipment from fire is to place an upper-limit temperature switch or thermal cutoff (TCO) in-line with the main power input. When temperatures rise above a safe operating range - as specified by various safety codes such as UL, CSA, or VDE — the TCO opens up, halting power flow into the system. Some TCOs switch power currents directly, while others drive an in-line power relay.

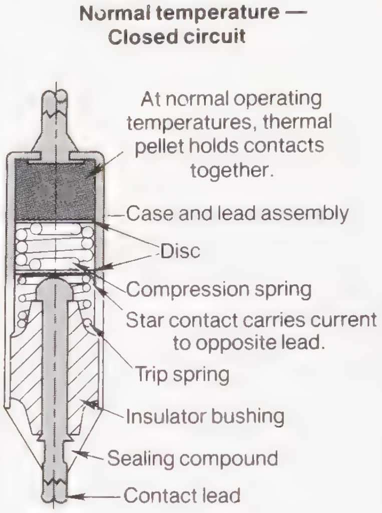
According to UL-1020, TCOs should produce only a single actuation. Such one-shot devices, sometimes called thermal fuses, must be replaced following actuation. Because TCOs normally backup the primary thermostat, their actuation indicates a major problem that requires professional servicing. Manual or automatic reset may permit dangerous temperatures to reoccur.

Several types of TCOs are available. A widely used type is the spring-and-pellet cutoff. Spring-and-pellet TCOs contain an insulating pellet which is the active trigger mechanism. Under normal operating temperatures, the solid pellet holds a pair of spring-loaded contacts together. At the break or fault temperature, the pellet melts, allowing the contacts to separate.

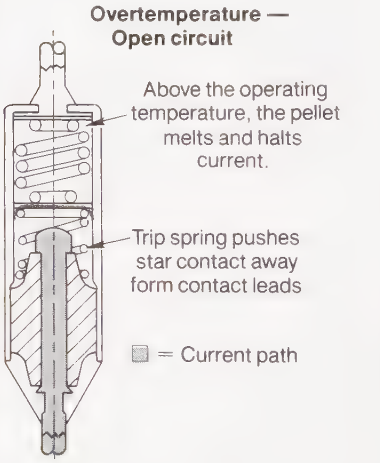
Most TCOs are small, have high current-interrupt capacity of up to 25 A, and have a low series resistance under 5 mΩ. A wide variety of lead configurations and mounting packages are also available.

One of the simplest types of one-shot cutoffs relies on a heat-sensitive alloy coated with a special resin compound. This thermal-sensing element is welded across a pair of radial or axial-lead wires. When temperatures reach the alloy's eutectic point, the resin compound generates a surface tension that pulls the liquefied element apart. Eutectic TCOs can be specified for various temperatures between 144 and 370°F and currents up to 7 A.

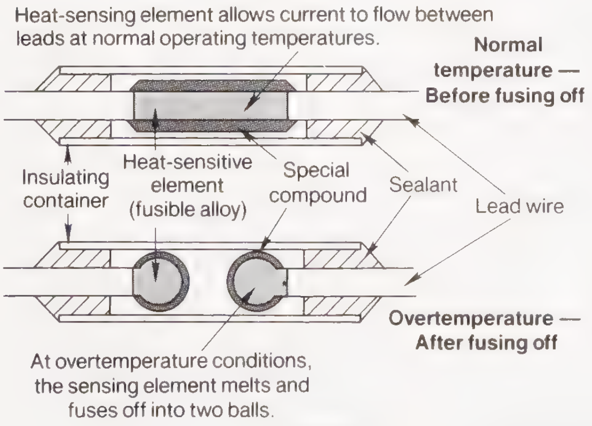
SPRING-AND-PELLET TCO


Normal temperature — Closed circuit
At normal operating temperatures, thermal pellet holds contacts together.
Case and lead assembly
Disc
Compression spring
Star contact carries current to opposite lead.
Trip spring
Insulator bushing
Sealing compound
Contact lead

Spring-and-pellet TCOs have direct-metal contacts, providing closed-circuit resistances of only a few milliohms. Upon temperature rise, the pellet melts and the star contact pulls away from the lead, breaking current flow. Once tripped, TCOs must be replaced to restore normal operation.


Overtemperature — Open circuit
Above the operating temperature, the pellet melts and halts current.
Trip spring pushes star contact away form contact leads
▨ = Current path

EUTECTIC TCO


Heat-sensing element allows current to flow between leads at normal operating temperatures.
Normal temperature — Before fusing off
Insulating container
Heat-sensitive element (fusible alloy)
Special compound
Sealant
Lead wire
Overtemperature — After fusing off
At overtemperature conditions, the sensing element melts and fuses off into two balls.

Eutectic TCOs rely on a heat-sensitive element that melts when temperature exceeds a set point. A special compound helps an alloy in the element to fuse off and permanently break the circuit.

LVDTs. In this case, a wiper is driven across a resistive coil, with output determined by wiper position. Compared to an LVDT, it has the added disadvantage of coil wear. If continuously operated in about the same pressure range, it may suddenly short out or produce severely nonlinear output. These sensors are rather inexpensive, however.

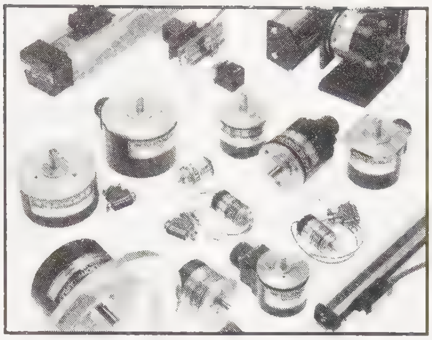
Electropneumatic transducers: These have long been used to provide regulated air pressures for the control of process systems. Typically, the accuracy required of such systems has not been critical; however, industry today is demanding far greater accuracy of its pneumatic control systems. This has spurred the development of a new generation of transducers that can control pressures with accuracies of ±0.25%.

These transducers can operate on electrical inputs of 1 to 5 mA, 4 to 20 mA, 10 to 50 mA, 1 to 5 Vdc, or 1 to 9 Vdc. These ratings correspond to a wide variety of industrial controllers and computers. Typical output of a transducer is a 3 to 15 psig pressure signal, which is nearly linear in relation to input current.

Transducer output flow is about 0.1 scfm at 15 psig, a rate that is too slow to actuate many components in a reasonable time. To overcome this problem, flow rate can be increased with the use of a volume booster. Volume boosters can be built into the transducer to boost output flow by any ratio required.

Optical Encoders from Teledyne Gurley...

When Performance Really Counts.



ROTARY INCREMENTAL ENCODERS

The chart below summarizes the salient features for comparison purposes. See individual data sheets for full details.

	The RED Line				The WHITE Line						The BLUE Line					
Model Number	8111	8114	8121	8125	8211	8214	8221	8225	8235	8235H	8311	8314	8321	8325	8335	8335H
Diameter inches	1.07	1.40	2.10	2.50	1.07	1.40	2.10	2.50	3.50	3.50	1.07	1.40	2.10	2.50	3.50	3.50
Max Length, inches (depends on options)	1.80	1.85	2.50	3.30	1.80	1.85	2.50	3.30	3.30	2.50	1.80	1.85	2.50	3.30	3.30	2.50
Shaft Diameter, inches	1/8	1/8 or 1/4	1/4	3/8	1/8	1/8 or 1/4	1/4	3/8	3/8	**	1/8	1/8 or 1/4	1/4	3/8	3/8	**
Max Line Count on Disc. (other counts avail.)	720	1024	2048	2540	1800	2540	4500	6000	10,800	10,800	1800	2540	4500	6000	10,800	10,800
Max Pulses per Revolution (4X)	2880	4096	8192	10,160	7,200	10,160	18,000	24,000	43,200	43,200	7,200	10,160	18,000	24,000	43,200	43,200
Max Pulses per Revolution (8X)	N/A				14,400	20,320	36,000	48,000	86,400	86,400	14,400	20,320	36,000	48,000	86,400	86,400
Max Pulses per Revolution (80X)	N/A				N/A						144,000	203,200	360,000	480,000	864,000	864,000
Duty Cycle Tolerance, ± elect. deg.	30				18						15					
Phase Angle Tolerance, ± elect. deg.	30				22.5	22.5	18	18	18	18	18	18	15	15	15	15
Incremental Accuracy, arc seconds	140	105	60	42	56	42	25	15	10	10	18	15	9	7	5	5
Absolute Accuracy, arc seconds	400	300	175	120	160	120	72	45	30	30	50	40	25	20	15	15
*Frequency Response, kHz 1x Square Waves or 1x Pulses	100				100						100					
4x Pulses	400				400						400					
8x Pulses	N/A				600						600					
80x Pulses	N/A				N/A						4000					
Operating Temperature °C	0 to 70				0 to 70						0 to 70					
FEATURES:	• ABEC Class 5 bearings • Unbreakable plastic disc • Resolution up to 4 times the line count on the disc				• ABEC Class 7 bearings† • Chrome-on-glass disc • Resolution up to 8 times the line count on the disc						• ABEC Class 7 bearings† • Chrome-on-glass disc • Dual reading heads • Resolution up to 80 times the line count on the disc					
	COMMON TO ALL MODELS • Reliable LED Illumination • Stable push-pull phototransistors • Optional zero index				• Combination synchro/face mount • Shielded bearings and non-contacting sleeve-type shaft seal						• Optional ferro-fluid shaft seal†† • Square flange mount (Series 825) • Heavy-duty housings available†					

***Index signal is fully functional up to maximum data rate.**
****Hollow-shaft encoder available with I.D. up to 1.26" and integral flexible coupling.**

†On high resolution versions. ††Series 821, 825 and 835.

MODULAR AND LINEAR INCREMENTAL ENCODERS

Rack-and Pinion Systems
Resolutions from 0.001 in (0.025 mm) to 10μ in (0.25 μm) over ulimited lenghts. Total system accuracy to ± 70μ in (1.8 μm) rms.

8708
1" x 1" x 1.75" non-contacting modular encoder. Linear resolutions to 0.0002" (5,000 pulses/inch) or 5 μm (200 pulses/mm). Rotary versions available in a wide variety of disc sizes and line counts.

8711
High speed, high frequency modular encoder. Provides 1Mhz disc data rate with synchronized index; up to 3 low frequency signals for commutation of brushless motors.

8717
1" x 1" x 1.75" non-contacting modular linear encoder. Resolutions to 10 μm (100,000 pulses/in) or 0.25 μm (4,000 pulses/mm) at 4Mhz.

8735
A rugged, enclosed linear encoder sealed against contamination. Scale can be 25 lines/mm or 500 lines/inch, up to 80" long. Optional external electronics increase resolution up to 80X.

8745
Enclosed linear encoder with 1" x 1 3/4" axis cross-section. Available in working lengths up to 48". Scale can be either 25 lines/mm or 500 lines/inch. Optional external electronics increase resolution up to 80X.

ABSOLUTE ENCODER SPECIFICATIONS

Model Number	25/04S	60/25H
Max. Resolution, words per turn	2^{17} (131,072)	2^{21} (2,097,152)
Max. Resolution, arcsec per word	9.888	0.618
RMS Accuracy at Data Transitions	± 3.2 arcsec	±0.25 arcsec
Outside Diameter, inches	2.5	6.0
Shaft Diameter, inches	3/8, solid	2.5, hollow
Body Length, inches	1.25	4.43
External Electronics size, inches	4.9 x 3.7 x 1.7 or IBM® card	8.8 x 6.8 x 1.9
Operating Temperature (standard)	-20 to +70°C	-20 to +55°C
Operating Temperature (optional)	-40 to +85°C	-40 to +85°C

Call for FREE application help and technical information 1-800-759-1844

Toll-free all 50 states and Canada.

TELEDYNE GURLEY
514 Fulton Street • P.O. Box 88 • Troy, NY 12181-0088
(518) 272-6300 • FAX: (518) 274-0336 • TWX (710) 443-8156

Circle 395

Strain-gage transducer characteristics

Sensor type	Excitation	Output level (mV/V)	Accuracy (%)	Pressure range	Frequency response	Temperature range and effects	Shock and vibration resistance	Stability (%/yr)
Sputtered thin film	10V ac-dc	3	0.25	25 psi through 10 kpsi	0 Hz to >1 kHz	−320 to + 500°F (0.005%/°F over limited compensated temperature range)	Very good	0.25
Unbonded	10V ac-dc	4	0.25	0.5 psi through 10 kpsi	0 Hz to >1 kHz	−320 to + 600°F (0.005%/°F over limited compensated temperature range)	Good	0.5
Bonded	10V ac-dc	3	0.5	5 psi through 10 kpsi	0 Hz to >1 kHz	−65 to +250°F (0.01%/°F over limited compensated temperature range)	Very good	0.5
Diffused semiconductor	10-28 Vdc or ac	3 to 20	0.1	0.10-in. H_2O to 0-10 kpsi	0 Hz to 500 kHz	−65 to + 250°F (0.002%/°F over limited compensated temperature range)	Very good	0.15

Practically all electropneumatic transducers operate on instrument-quality air, at 20 ±2 psig. This is essentially clean, oil-free air and is recommended to ensure the reliable operation of the nozzle/orifice combination. Some transducers, however, can operate on reasonably clean shop air at supply pressures to 150 psig. Modifications made to allow operation on such air include the use of a larger nozzle and a 40-μm air filter.

Electropneumatic transducers typically are of three basic types: voice-coil beam, voice-coil beam dampened by an oil dashpot, and torque motor.

Voice-coil beam transducers use a nozzle/flapper arrangement to convert a small mechanical motion into a proportional pneumatic signal. The flapper arm is attached to the transducer base by a flexure strip. Various nozzle/flapper arrangements are used but the basic operation of each is similar.

In operation, current passes through the coil, and the resultant magnetic field reacts with that of a permanent magnet to move the coil assembly up or down. The resultant thrust on the coil is transmitted to the flexure strip to vary the position of the flapper, controlling air flow through the nozzle and varying output pressure in proportion to the current passing through the coil.

Damped transducers operate in a similar manner except that the arm controlling flapper position is attached to a float suspended in silicone oil. The oil dashpot effectively isolates the nozzle/flapper from vibration. However, it has the added effect of slowing response time. Such transducers also are sensitive to mounting angle because the oil can leak out. Typically, mounting angle is limited to about ±10°.

Torque-motor transducers also have similar operating principles, except that a conventional torque motor replaces the voice-coil beam arrangement to position the flapper. An advantage of such transducers is that the torque motor maintains its position even under fairly severe vibration.

Of the three types, voice-coil beam transducers are the most widely used. In this group are units that range from low-cost devices used in some HVAC systems, which do not require great ac-

Temperature switch specification summary

Differential-expansion bimetal	
SNAP-ACTING DISC	−20 to 1,490°F
Tolerance	±17 to ±25°F
Operating differential	3 to 30°F
Cycle life	100,000 cycles
Power handling	50 A at 480 Vac
STRUT-AND-TUBE	
Temperature range	−100 to 1,500°F
Tolerance	±3 to ±5°F
Operating differential	0.1°F to 100°F
Resolution sensivity	0.1°F
Power handling	10 A at 120 Vac
Liquid filled	
BULB-AND CAPILLARY	
Temperature range	−200 to 1,200°F
Operating differential	3 to 4°F
Power Handling	15 A at 120 Vac
LOCAL	
Temperature range	0 to 425°F
Reed switch	
Temperature range	0 to 482°F
Tolerance	±5 to 10°F
Operating differential	10°F
Cycle life	3,000,000 cycles
Power handling	1 A at 120 Vac
Mercury-in-glass	
Temperature range	−40 to 500°F
Tolerance	±0.05°F
Cycle life	1,000,000 cycles
Power handling	25 mA at 115 Vac

SILICON PRESSURE CHIPS

A piezoresistive strain gage is used as a transducing element in semiconductor pressure sensors. A millivolt-level output results when pressure is applied to a silicon diaphragm containing integral-sensing (resistive) elements. This low-level output has a wide tolerance on zero and full-scale output. Temperature also affects these parameters.

Designers can use a basic element and add circuitry for the application or consider using a sensor that the supplier has compensated and calibrated for temperature. The choice depends on operating temperature range, application requirements, and ability of the user to manufacture products containing semiconductors.

In many cases, the low (millivolt) level output of the sensor is inadequate for use in subsequent stages without additional amplification. All manufacturers provide information on how to convert the output of their sensors to a suitable voltage level.

A common requirement is the connection of a sensor to an analog-to-digital (a/d) converter, which provides digital information for a microprocessor. A 0.0 to 5.0-V signal utilizes the full range of many a/d converters for maximum accuracy.

curacy, to higher-cost precision units that provide accuracies of ±0.25% or better on linearity and hysteresis combined. Voice-coil units also are typically smaller and lighter than oil-damped or torque-motor types.

Oil-damped transducers usually are heavier and more costly than simple voice-coil devices, but they provide more stable operation when subjected to vibrations of up to 100 Hz (and sometimes as high as 200 Hz). However, absolute distinctions are difficult to make in this regard because the industry is only now beginning to characterize the performance of electropneumatic transducers under vibration loads. Preliminary test results indicate that damped transducers may provide an advantage over new lightweight undamped units only at frequencies below about 10 Hz.

Torque-motor transducers also provide accuracies as high as ±0.5% and are extremely stable. However, they can weigh three to four times as much as voice-coil units and cost three to five times as much.

Accelerometers

Not long ago, the only accelerometers available employed either a quartz crystal or moving coil. Typical costs of these devices were $500 or more. Now, a new generation of solid-state devices is smaller and lighter than its predecessors and is less expensive as well. Some of the new accelerometers cost only about $50, but cannot handle certain kinds of applications. In fact, choosing an accelerometer sometimes can be harder than using one.

One of the more commmon accelerometers is called a suspended-mass type. Suspended-mass accelerometers are characterized by their small size (solid-state devices are about as big as a transistor) and ability to respond to dc (static) accelerations. Frequency response ranges from dc to about 5 kHz depending on the particular type. High-g-range units generally have higher frequency response than their low-range equivalents. A simple model of such a device is a mass suspended on the end of a cantilever beam, but actual devices are more complicated.

For instance, the new solid-state versions of this type suspend a silicon mass from four deflection beams. The mass and beams are in a cavity in the silicon structure.

Two features usually protect the beams from overflexing. In addition to protecting the accelerometer, these mechanisms also affect its measuring capabilities. The first safety device is a mechanical stop. It protects the beam from damage during peak accelerations. Second, oil provides viscous damping. Damping also increases the accelerometer's frequency response and prevents damage from frequencies near the beam's resonant frequency.

Suspended-mass devices use two different methods to determine acceleration. The first method is to measure the force (strain) induced in the beam by the mass. Here, strain gages on the beam generate a signal proportional to acceleration. A bridge circuit connects the four strain-sensing elements. The result is a device having performance similar to that of standard piezoresistive strain-sensing elements. Accelerometers of this design are usually called strain-gage bridge accelerometers, regardless of the type of strain sensing element used.

Rather than gaging deflections with strain gages, some suspended-mass devices use capacitive sensing. This gives an electrical signal proportional to the mass's displacement. An advantage of some capacitive accelerometers is that they are air damped. This makes their damping coefficient relatively insensitive to temperature, unlike fluid-damped devices.

The most rugged of all accelerometers is the piezoelectric type. A typical unit, rated 10,000 g, is housed in a cylindrical package about 1 in. long by ¼ in. in diameter. Piezoelectric transducers also offer a wider temperature range (−195 to 260°C) than any other accelerometers.

The frequency response of these devices is wide because the active sensor is small. Most units have a frequency range of at least 5 kHz. Typical reso-

PIEZOELECTRIC MATERIALS

Piezoelectric transducers convert an electrical signal to physical motion, or vice versa. Sensor material is usually a ceramic based on titanates of barium or lead zirconia. The rigidity of the ceramics makes them especially suited for converting electrical energy to mechanical motion in applications such as audio speakers or signalling alarms. But ceramics are brittle and cannot be made with large surface areas or in complex shapes.

A new piezoelectric material based on polyvinylidene fluoride (PVDF), however, overcomes such drawbacks. Large thin sheets of the material can be cut or stamped into nearly any shape. The flexible film provides less transducing power than ceramics, especially at low frequency. It is also more sensitive to mechanical stress, withstands higher voltage, operates over a broader frequency range, and responds to a wider degree of mechanical stress. These qualities make it superior to ceramics for many sensor applications.

Application of a dc voltage across the piezo film makes the material thinner, longer, and wider in proportion to the voltage level. Reversing the voltage makes the film thicker, shorter, and narrower. Strain constants define the relationships between applied voltage and the induced mechanical strain. The constants have different values for each axis.

Similarly, the film generates a proportional voltage when compressed or stretched. Stress constants define the relationship between applied mechanical stress and generated voltage. There is one constant for each axis.

Piezo film also produces an electrical signal when exposed to infrared light. Heat induces mechanical stresses in the material. A pyroelectric constant defines the resulting voltage.

The film is more sensitive to stretching than to compression, a result of the higher values of mechanical stress. For example, stretching the film can produce peak voltages from about 20 to 30 V. Approximately the same result is obtained by bending the film over a sharp corner, an alternate and often convenient way of stretching the material.

The g-constants (representing voltage generated in response to stress) for piezo film run from 10 to 20 times that of ceramics. The constants for both PVDF and ceramics are proportional to the electrical charge constant and inversely proportional to the dielectric constant. The electrical charge constants for the two materials are of the same order of magnitude. But the dielectric constant of film is usually 12, through some have values up to 18, compared to 1,200 for ceramics. Thus, for a given voltage, a film sensor can be much thinner and lighter than a similar ceramic device.

The piezoelectric qualities of PVDF film are stable at temperatures up to about 70°C. When suitably treated, the film is stable up to 100°C but unfit for exposure to temperatures above that level. Dynamic sensitivity runs from about 10^{-8} to 10^{6} N/m, a 286-dB range.

nant frequencies are over 30 kHz.

Though tough, the devices are not without their problems. One is that they do not respond to static accelerations. For instance, typical units have a minimum response in the range of 0.01 to 5 Hz. But a bigger concern is with the output.

For accurate measurements, the accelerometer and cable must be calibrated as a system. If the cable length is changed, another calibration is required.

The alternative is to measure the charge generated by an acceleration. This techniques negates cable effects, but requires a charge amplifier. Compared with other amplifiers, charge amplifiers are expensive.

Another problem associated with piezoelectric accelerometers is the need to maintain high insulation resistance and low noise in the cabling between the accelerometer and the charge amplifier. Otherwise, measurement errors will be introduced into the system. Generally, the cable must be of special low-noise type (supplied by the accelerometer maker) and must be fastened in place to reduce vibration-induced electrical noise.

As an alternative to an external amplifier, some manufacturers offer piezoelectric accelerometers with built-in amplifiers. These devices overcome the cabling and amplifier problems. They also have low output impedance. This means that connecting them with oscilloscopes or chart recorders is relatively easy. The primary disadvantage of internally amplified units it that they require a separate power supply.

Another common accelerometer is the electromechanical force-balance type. These are commonly called servo accelerometers because they use a closed-loop control system to measure acceleration.

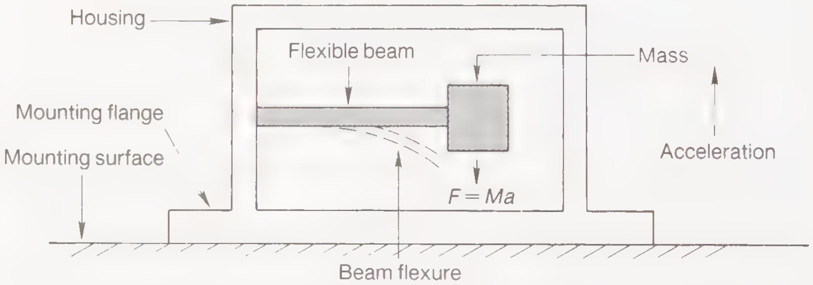
Mechanically, the devices consist of a permanent magnet and a sensing mass attached to a moving coil. Servo accelerometers also require some internal circuitry generally consisting of a position sensor, error amplifier, and a voltage-to-current (V/I) converter.

The sensor output represents the location of the sensing mass with respect to a null or center position. An error amplifier and V/I converter change the position signal into a current which drives the moving coil.

The moving coil and permanent magnet exert a force on the mass. The force is proportional to the current in the coil. When the mass begins to move away from the null position because of an external acceleration, the position error generates a coil current, returning the mass to the null position. A voltage signal representing coil current is used as the accelerometer output signal.

One variation in the construction of the servo accelerometer uses a bobbin-shaped coil mounted on a disc. The disc supports the coil with two beams, allowing the coil to move axially. The coil is surrounded by a permanent magnet. Current forces the coil into a null position in response to external accelerations. The advantage of this structure is high reliability because the coil needs no pivot.

BEAM-TYPE SUSPENDED-MASS ACCELEROMETER



Suspended-mass accelerometers generally use either of two methods to measure acceleration. One way is to implant resistors in the flexible beam. The difference in the signal from two beams is proportional to acceleration. In the other method, the mass and the housing form the two plates of a capacitor. The distance between the two and the resulting capacitance changes as a function of acceleration.

		SUSPENDED MASS		
Parameter	Servo	Strain gage or unamplified piezoresistive bridge	Unamplified solid-state	Piezoelectric
Full scale range(g)	±10	±100	±100	±500
Overload	100	1,000	2,000	2,000
Resonant frequency (Hz)	140	5,000	2,750	40,000
Frequency response (Hz)	0-70	0-1,300	0-1,600	1-5000
Sensitivity	±5Vdc @ F.S.	5mV/g	±50mV.F.S.	10mV/g
Non linearity	±0.1% of F.S.	±2% of F.S.	0.2% of F.S.	±1% of F.S.
Gain accuracy	±1% of F.S.	NA	NA	±2% of rated
Offset accuracy	0.1% of F.S.	±25mV	±5mV	NA
Gain temperature coefficient	0.02% per°C	5% over −18 to 93°C	±0.3% of F.S. over to 50°C	−0.06% per °C
Offset temperature coefficient	0.002% per °C	±20m V over −18 to 93%°C	±0.3% of F.S. over 0 to 50°C	NA
Transverse sensitivity	±0.002g per g	3%	1% of F.S.	5%
Resolution	0.001% of F.S.	Unspecified	Unspecified	0.01 g rms
Input inpedance (Ω)	NA	1,800	3,500	NA
Output impedance (Ω)	<10k	1,400	3,500	100
Supply voltage (Vdc)	±15	10	5	20-30
Supply current (mA)	25	NA	NA	4mA
Weight	4 oz	1 oz	1.2 grams	12 grams
Operating temperature range (°C)	−55 to 95	−18 to 93	−40 to 125	−55 to 120
Damping ratio	0.6	0.7	0.7	NA

Servo accelerometers typically require supply voltage of ±15 Vdc. Output signals of ±5 V are typical. Because the structure is bulkier than suspended-mass accelerometers, frequency response is lower. Most units do not respond above a few hundred cycles/sec. These accelerometers usually come with mechanical stops or fluid dampers to prevent damage from accelerations beyond their range.

Frequency response is often the single most important issue in selecting accelerometers. A primary concern is whether response to static accelerations, such as gravity, is needed. If so, use a suspended-mass or servo type. Of the two, suspended-mass types are more durable.

However, most applications do not really need static response. Instead, the response must simply be close to dc. Piezoelectric accelerometers have low (0.01 to 5-Hz) frequency cutoff but do not respond to static acceleration. At the high end of the frequency response spectrum (above a few thousand

This Technology Goes Over A Lot Of People's Heads.

Our pressure transducers have delivered thousands of hours of high performance on 747's, B-1 Bombers, F-16's and Blackhawk Helicopters. You can expect the same from the models we build for your applications. Our absolute, differential and barometric pressure transducers feature superior repeatability and long-term stability. So they're perfect for any application where accuracy and reliability are critical. For more information call (612) 892-4461, or fax Marketing Communications at (612) 892-4430.

ROSEMOUNT®

Measurement
Control
Analytical
Valves

Circle 396

Rosemount Inc.
Aerospace Division
14300 Judicial Road
Burnsville, MN 55337

They're Boldly Going Where No Man Has Gone Before.

Our platinum resistant temperature sensors are on the Space Shuttle and the Galileo Space Probe. They're also right for your applications where accuracy and reliability are critical. Our standard surface and immersion models can fulfill compatibility, time response, size and environmental requirements. And our engineering support means we can provide custom solutions you won't find in a catalog. For more information call (612) 892-4461, or fax Marketing Communications at (612) 892-4430.

ROSEMOUNT®

Measurement
Control
Analytical
Valves

Circle 397

Rosemount Inc.
Aerospace Division
14300 Judicial Road
Burnsville, MN 55337

Hertz), only piezoelectric devices operate properly.

Another important consideration is g-level range. This determines the maximum g load a device can measure accurately. It also indicates the maximum acceleration that a device can withstand without damage or permanent scale shift. It should be noted that the maximum acceleration encountered can be substantially higher than expected, because of incorrect mounting or loose parts. Except for servo accelerometers, other types withstand shocks over several thousand g.

Working temperatures can also influence selection. Piezoelectric accelerometers with separate charge amplifiers have the widest temperature ranges.

An accelerometer has a temperature stability specification, which influences performance. Temperature stability has two facets: thermal gain shift and thermal zero shift. Thermal gain shift tells how much temperature changes accelerometer sensitivity. This is usually expressed in percent of full scale per degree.

Thermal zero shift is the amount of accelerometer output shift caused by temperature changes with no acceleration applied. This is given in percent of full scale per degree.

Servo accelerometers generally have the best temperature stability, but specific temperature ranges must be considered. Temperature shift is usually nonlinear and must be considered over the range in which the unit will be used. As might be expected, operating the device in a narrow temperature band minimized these effects. Depending on the device, full-scale changes over the rated temperature range vary from (0.1% to 10%). Some accelerometers also have ratings for storage temperature that differ from the operating temperature limit.

SENSOR TIPS

Although proximity sensor design varies, manufacturers offer some common warnings, tips and advice. Some of the most important are:

Each type of proximity sensor has its own peculiarities. For example, inductive sensors do a poor job detecting aluminum, but work well with mild steel. Hall-effect sensors sometimes generate false signals when the machinery they are mounted on becomes magnetized. Capacitive types can be sensitive to environmental capacitance and humidity, and photoelectrics can be unreliable in dirty conditions.

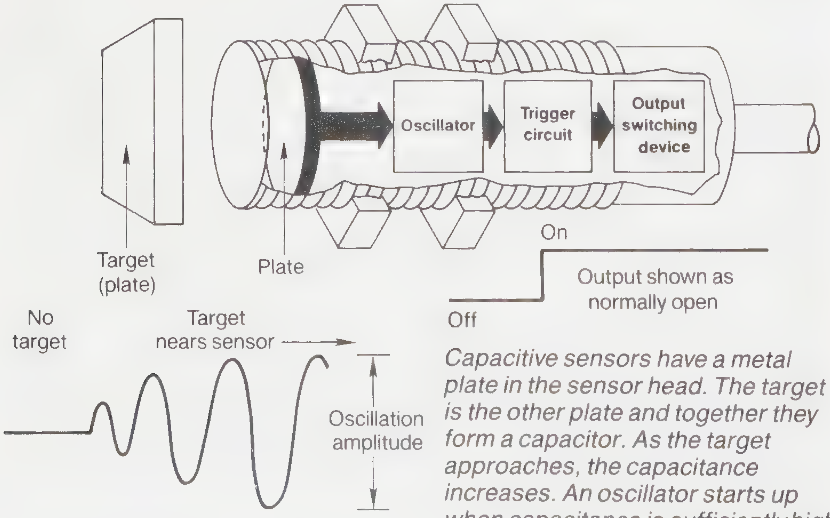
Two-wire (either ac or dc) sensors must have a load applied before being powered up. Otherwise, the sensor could be ruined. Furthermore, incandescent lights or motors should not be used as loads. The high inrush current of these devices destroys the sensor.

Most three and four-wire sensors operate either as current sinks (*npn*) or sources (*pnp*). While it does not matter which type is used for loads such as counters or relays, the choice is critical for programmable controllers. If the wrong type is used, the system will not work and the sensor or PC could be damaged.

Some types of inductive and capacitive sensors have become commodity items, with little difference between the devices offered from one manufacturer to the next. Typically, these are the simple "no frills" sensors. In addition, several sensor suppliers simply resell private label devices made by other companies.

Proximity sensors detect objects without physical contact. Most proximity sensors emit an electromagnetic field or beam and look for changes in the field. The object being sensed is called a target. Different targets demand different sensors. For example, a capacitive or photoelectric sensor might be suitable for a plastic target; an inductive sensor requires a metal target.

In capacitive proximity sensors, the sensed object changes the dielectric constant between two plates. Sensing range is usually quoted relative to water. Because changes in capacitance take a relatively long time to detect, the upper switching range of these devices is about 50 Hz. Primary applications are in bulk-handling machines, level detectors, and package detection. One advantage of capacitive sensors is that they are unaffected by dust or opaque containers, allowing them to replace optical devices.



Capacitive sensors have a metal plate in the sensor head. The target is the other plate and together they form a capacitor. As the target approaches, the capacitance increases. An oscillator starts up when capacitance is sufficiently high.

A typical capacitive proximity sensor has a 10-mm sensing range and is 30 mm in diameter. The device incorporates a potentiometer to allow fine tuning of the sensing range and can repetitively detect objects within 0.01 mm of the set point. Switching frequency is 10 Hz, and operating temperature range is −14 to 158°F.

Conditioning the output of position sensors has always been difficult. Designers must confront problems of linearity, hysteresis, excitation voltage instability, and voltage offset.

Circuits that measure current flow between the sensing electrode and the target surface provide readouts in appropriate engineering units. Usually, one side of the voltage source or oscillator connects to the sensing electrode, and the other side connects through a current-measuring circuit to the target surface, which generally is a metal part at earth or ground potential.

Probes used with capactive proximity sensors have either a flat disc or rectangular sensing element surrounded by a guard electrode that provides electrical isolation between the sensing electrode and its housing. The guard also insures that the lines of electrostatic field emanating from the probe are parallel and perpendicular to the surface of the sensing electrode.

Capacitance systems can make measurements in 100 μs with resolutions to 10^{-7} in. (0.001 micron). Probe diameters range from a few thousandths of an inch to several feet for corresponding measurements ranging from thousandths of an inch to several feet.

Probe selection depends on the material to be sensed. Probes for sensing nonconducting surfaces or insulators vary slightly from those for conducting surfaces. Nonconducting probe signals are also more difficult to linearize.

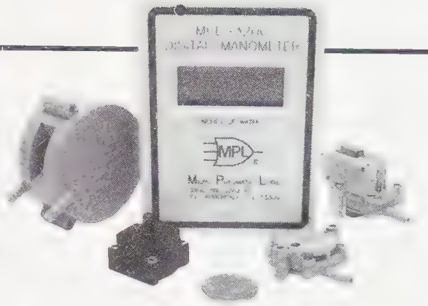
As standoff distance decreases, required probe size decreases. But if the ratio of sensor area to gap width is too small, signal current will be too weak to measure accurately. A probe-to-target capacitance of about 0.25 pF corresponds to a safe maximum standoff distance. This is the capacitance produced by a 1 sq-in. plate spaced 1 in. from a large conducting surface. If plate area is 0.1 in.^{2} (0.33 in. on a side), then a 0.1-in. spacing produces the same capacitance, and so forth.

When measuring the distance to a conducting surface, probe-tip size should be small when compared to the conducting surface for maximum linearity and accuracy. If the probe tip is approximately the same size as the measured surface, capacitance changes caused by gap-width variations are not distinguishable from those caused by target surface-area changes between samples. Therefore, the distance between the target surface edges and sensor edges should be at least three times the gap length.

If the target surface cannot extend beyond the probe-tip edges, then probe tip dimensions may exceed those of the target surface. However, the measurement will be affected somewhat by variations in part size. In general, if the target surface is large and stationary, the largest probe possible is used. However, little is gained by increasing probe size once sensor capacitance exceeds 1 pF.

In addition to round and square probe shapes, a variety of configurations are available for specific tasks. For example, if required resolution for a moving target surface is finer in one direction of motion than that for a direction normal to the first, then a rectangular probe can be used. Here, the narrow dimension is aligned in the direction requiring the best resolution. This technique is used to measure radial wave crests on a rotating disc, or radial and axial edge runout of hollow cylindrical objects.

For measuring internal conical sur-



Now MPL Covers All Pressure Points

For years the MPL name meant miniature pressure switches alone. Now we offer miniaturized transducers as well as switches--tailored to your specific applications at far less than custom prices--plus pocket-size digital manometers.

In a word, you can have MPL low-cost solutions for *all* OEM pressure monitoring and control problems, including:

☐ Pressure sensing from 0.0015 psi to over 100 psi,
☐ Proportional mA output signals, in ranges, from 0-100 psi, tailored for RS-232, 20mA transmitters or other uses.
☐ Current switching from 10mA to over 25A with high hysteresis or zero hysteresis.
☐ Pressure measurements with direct digital readout.
☐ Reliability measured in millions of cycles in automotive, computer, HVAC, medical, process control, and many other commercial and industrial applications.

Call today for a free information kit.

Micro Pneumatic Logic, inc.
2890 N W 62nd Street, Fort Lauderdale, FL 33309-1786
Tel: (305) 973-6166 Fax: (305) 973-6339

Circle 398

Crouzet INDUSTRIAL GRADE LIMIT SWITCHES

- Meet International Standards
- High Electrical Performance Capability.
- Rugged Resistance to Accidental Impact.
- High degree of protection against water, oil, and dust.
- Wide Range of Actuators
- Easy Connection - 1/2" NPT Fittings

Call us for a free catalog!
800-677-5311 FAX: 214-250-3865

Circle 399

no other
OEM electronic
components
give you "the
run for your
money"...like

Burgess
SAIA

- Innovative designs in the widest range of styles available.
- Snap switch performance measured in millions of operations.
- Precision-Made of the finest materials. to ensure long-life, durability and performance.
- Designed to exceed every safety and quality standard "worldwide".
- Our Ultra, Micro and Sub-Miniature switches offer flexibility and options that go beyond the industry, offering creative thrust to OEM engineers and designers.
- Gear boxes, synchronous, stepper motors (with the highest torque per inch in the market)...and Swiss-Made.
- Our TOK key & rotary security switches offer up to 100 million different combinations and are custom built.

Simply stated, Burgess-SAIA brings you the best selection and widest range of quality switches, motors and gear box products on the market... no one offers better.
For more detailed technical information or engineering support contact:

Burgess
SAIA, INC. Switch & Motor Divisions

SAIA
1335 Barclay Boulevard
Buffalo Grove, IL 60089
Tel (1-708) 215-9600
Fax (1-708) 215-9606

BASICS OF PROXIMITY SENSORS

Although there are many variations, three basic types of devices are categorized as proximity sensors: electromagnetic, optical, and ultrasonic. Electromagnetic types are subdivided into inductive and capacitive sensors. Most inductive sensors respond to the presence of any metal. But ferrous metal gives the best response, about two-thirds higher than nonferrous metals.

One common principle of operation for inductive sensors involves an eddy current killed oscillator (ECKO). The oscillator is a tuned *LC* tank circuit and amplifier. A sensor coil and ferrite core make up the inductor. The amplifier provides just enough positive feedback to make the circuit oscillate. The frequency of oscillation is in the RF range.

When metal is near the sensor face, the RF field causes eddy currents to flow in the metal surface. The eddy currents place a load on the oscillator. At some point, depending on the sensor sensitivity, the load is enough to stop the oscillator. A level detector connected to the *LC* circuit them produces an output.

Usually a certain amount of hysteresis (differential travel) is built into the sensor. The purpose of the hysteresis is to prevent chatter when the target sits right at the oscillation threshold point.

Capacitive sensors also use an oscillator to sense their target. However, instead of turning off when the target is present, they turn on.

The sensor head has a metal plate which forms one half of a capacitor. The target is the other plate. As the target approaches the sensor, oscillator feedback capacitance increases. The circuit begins to oscillate with sufficiently high capacitance.

Optical proximity sensors use one of two basic principles, reflection or through-beam. Reflective devices sometimes house the light source and detector in one housing.

Most reflective sensors use either diffuse or specular reflections. With diffuse reflection, light scatters in many directions. Shiny surfaces give specular reflections. A third type of reflective detector uses a retroreflector (similar to a bicycle reflector) to reflect the beam. The target breaks the beam but does not reflect it.

Through-beam sensors operate in a similar manner. However, unlike retroreflective devices, the light source and detector are in separate packages. This scheme has the advantage of longer range and greater contrast ratio over reflective sensors.

Ultrasonic proximity sensors share some traits with reflective light devices. For example, ultrasound waves follow the same laws of reflection: The angle of incidence equals the angle of reflection. And the same law (the inverse square law) governs sound intensity. For example, if the sound intensity one foot in front of the sensor is used as a reference level the intensity at two feet is one-quarter as much.

Ultrasound sensors have their own peculiar traits. One is that the target density affects the strength of the reflected sound. The denser the target, the better the sound reflection. A second is that the speed of sound depends on the ambient temperature and relative humidity. The result is that a drop in temperature moves the sensing area away from the sensor; an increase has the opposite effect.

To offset these variations, some manufacturers offer a special temperature compensation reference target. The device is essentially a U-shaped wire. The wire ends fasten to the sensor. The bottom of the U provides a reference point a fixed distance from the sensor. The sensor measures the time required for an echo to return from the reference target and compensates for the temperature. Some manufacturers offer proximity devices that also use reflections to detect an object. However, instead of sound waves, they use microwaves. The devices measure the Doppler (frequency) shift in the microwaves caused by the target. The sensors can detect objects and also measure velocity.

The trend in proximity sensors is toward smaller and more rugged packages. Signals from today's sensors are more linear than their predecessors because thin-film laser-trimmed resistors are being used in the output amplifiers.

The electronic circuitry, and usually the output switching means, are contained in the control unit. Most units allow installations in NEMA-1 or NEMA-12 enclosures. In nearly all units, provision is made for sensitivity adjustment. A locking-type potentiometer is most commonly used. Connections to the sensing head, ac line power, and output contacts are made through standard barrier-type terminals. Where relays are used, the control unit should be mounted on surfaces free from excessive vibration or shock.

Relay contact ratings range from 2 to 25 A at 115 V. Both spdt and dpdt contact configurations are available. Solid-state output switching is available for currents in the order of 100 mA to 5 A and voltages from 9 to 48 Vdc are typical. Solid-state switching is also available for ac circuits with currents up to 5 A and voltages up to 115 Vac. Completely transistorized proximity switches with static switching approach infinite life.

faces, sensors are mounted inside cone-shaped probes. This is useful for measuring valve-seat runout. A probe array can measure surface flatness. Here, each probe is electronically zeroed against a known flat surface. Electronic modules automatically scan the outputs of probes, indicating average deviation from standard, the highest and lowest deviation from the average, and the difference between them.

Light sensors often use an infrared LED as a light source. Infrared LEDs have a greater intensity than LEDs that emit visible light. And when infrared photodiodes are used the sensors are relatively insensitive to ambient light.

Photoelectric light sources are often modulated at a given frequency to prevent interference from ambient light. But flashes or reflections can still fool light-activated sensors. This problem is solved by using a modulated receiver. Here the detector is synchronized to the light source frequency. For example, suppose emitted light has a frequency of 5 kHz, with a pulse duration of 10 μs. The emitter LED and detector need only be on for 10 μs. They can be off for the 190 μs that light is not transmitted. Such third-generation devices have fewer false signals because the chance of ambient light activating the receiver is only 1 in 19.

One trend in photoelectric sensors is the development of modular devices. Sensor heads can be combined with a separate base and power supply, and with various logic options. The approach tailors a sensor for particular needs. Another advantage is that sense heads or logic options can be changed in the field without disturbing wiring or beam alignment. This minimizes downtime and allows unskilled personnel to repair equipment.

Fiber optics also are turning up in photoelectric sensors, both as optional sense heads, or integral to the sensor itself. The technology has a number of advantages over conventional methods such as through-beam or reflective sensors. Fiber-optic cables are small, some are only about 1/16 in. in diameter and the fiber-optic head is usually just a little larger. As a result, it can fit into tight spaces. Fiber optics can also be used in explosive environments because all electrical signals are remote. Similarly, optic cables can reside next to high voltage cables in plenums.

Reflective light sensors (RLSs) are frequently employed to sense an object's presence because they are easy to use. An RLS differs from other light sensors in that the target does not simply break a light beam but reflects light to a detector.

Through the years, RLSs have been refined so that they are less sensitive to ambient light and can detect minute or transparent objects. Some devices can even determine the distance between sensor and object, thereby offering an alternative to ultrasonic systems.

While in general, RLSs are becoming smaller, two divergent trends are emerging as well. One group of sensors is becoming simpler, basically containing only a light source and detector. Sensor output is a simple on/off signal, and users provide the power supply and signal processing circuitry.

The other group is becoming full featured. These devices contain a power supply and logic. Users program the device by setting switches or with a PC.

Simplicity has not come at the cost of technological innovation or accuracy. Sensor manufacturers are integrating advanced devices like solid-state lasers into their devices. Usually the power supply for the laser and an amplifier for the signal output are contained in a separate unit. An advantage

SOMAT®

DO YOU KNOW HOW *YOUR* PRODUCT IS *REALLY* BEING USED?

How do you get that information?

When you want in-service data and analysis fast and easy, SoMat has the solution for you with our family of Field Computer Systems! For about $1000 a channel, you get the information you want, and you also get SoMat support. You can count on it!

One customer says *"If more companies were as cooperative after the equipment was purchased like SoMat, my job would be a lot easier..."*

Other customers comment: *"SoMat really listens and develops what the customers ask for." "Now we have extensive field testing, not just with our in-house machines. We have an edge over our competitors." "First rate in every respect."*

SoMat II software is at the head of the family of Field Computer Systems and runs the entire Field Computer family from calibration and test setup, to display immediately after the test, to analysis of the information collected. Strains, torques, loads, accelerations, pressures, temperatures, voltages, Hall Effect sensing, encoders, frequencies — If you need field testing capability, call us at (217) 328-5359.

SoMat — when timely results matter

Circle 401

of placing system functions in different packages is that the sensor is kept small.

Power semiconductors and ICs

Transistors are three-terminal semiconductor devices. One terminal controls electrical resistance or current flow between the other two terminals, giving transistors a valvelike operation. They can amplify signals over some linear range of voltage and current or they can rapidly switch signals between two or more levels. Typical transistor switching circuits include inverters, converters, voltage regulators, and relay and solenoid drivers.

Transistors are grouped into two categories: bipolar-junction transistors (BJTs) and field-effect transistors (FETs). The two different types of field-effect transistors are metal-oxide semiconductor (MOSFETs) and junction (JFETs).

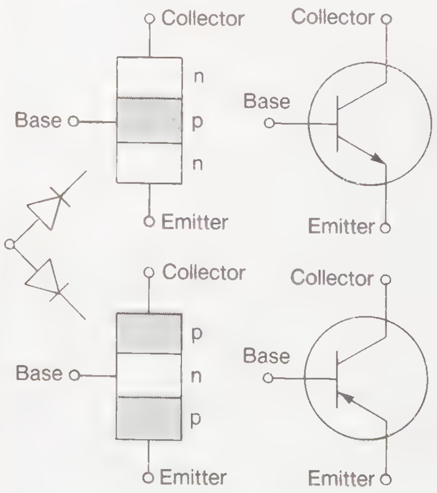
BJTs: Bipolar junction transistors are composed of two *p-n* junctions formed by three layers of semiconductor material. The layers are called the emitter, base, and collector. An electrical signal (current) applied to the base terminal controls the current between the emitter and collector.

The emitter and collector are both made from the same type of material, *n*-type in *npn* or *p*-type in *pnp* transistors. *N*-type material is negatively doped to have excess electrons, and *p*-type positively doped to be deficient of electrons. In either case, the base material is opposite that of the emitter and collector. The two types of BJTs can be differentiated in schematic diagrams by their circuit symbols.

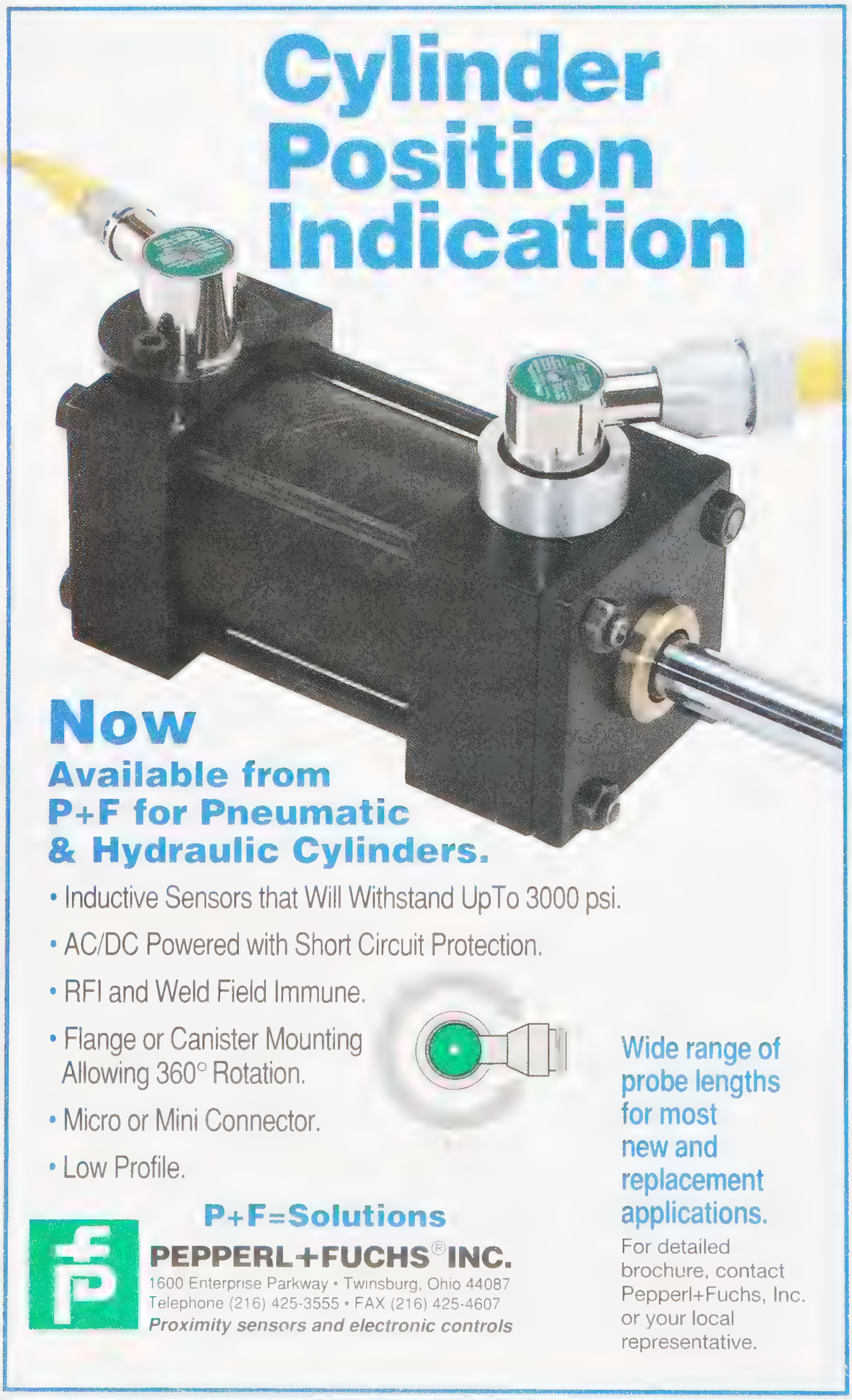
Among the most important transistor characteristics are maximum V_{ce} (voltage between collector and emitter), I_c (current flowing through the collector), power dissipation, and maximum allowable junction temperature (collector junction). Exceeding these values may damage the transistor.

JFETs: Junction field-effect transistors are composed of an *n* or *p*-type semiconductor channel with two electrical contacts, source and drain, at opposite ends. Two junctions, of opposite polarity with respect to the channel, laterally bound the channel along its length. The two junction contacts are normally tied together and called the gate. In schematic diagrams an inward-pointing arrowhead on the gate lead signifies an *n*-channel JFET. An outward pointing arrowhead is used for a *p*-channel JFET.

An electrical signal applied to the gate terminal controls the channel resistance between the source and drain.



Bipolar junction transistors have three terminals: the base, the collector, and the emitter. Their circuit diagram symbols differentiate between npn or pnp versions.


Cylinder Position Indication

Now Available from P+F for Pneumatic & Hydraulic Cylinders.

- Inductive Sensors that Will Withstand UpTo 3000 psi.
- AC/DC Powered with Short Circuit Protection.
- RFI and Weld Field Immune.
- Flange or Canister Mounting Allowing 360° Rotation.
- Micro or Mini Connector.
- Low Profile.

Wide range of probe lengths for most new and replacement applications.

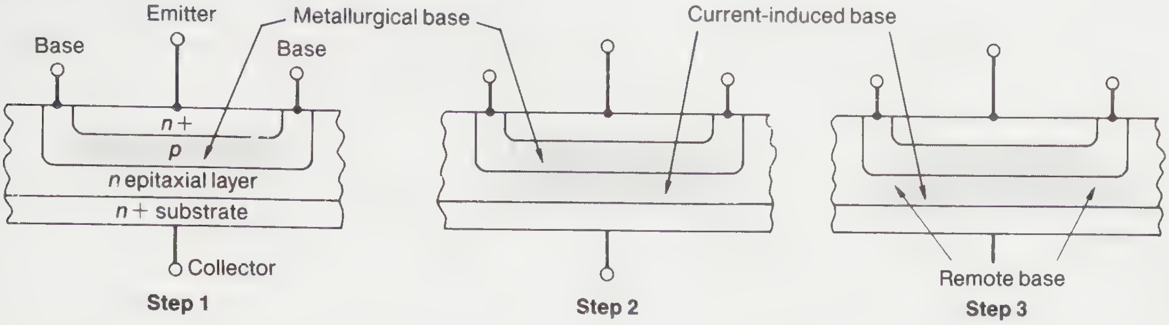
P+F=Solutions

PEPPERL+FUCHS® INC.
1600 Enterprise Parkway • Twinsburg, Ohio 44087
Telephone (216) 425-3555 • FAX (216) 425-4607
Proximity sensors and electronic controls

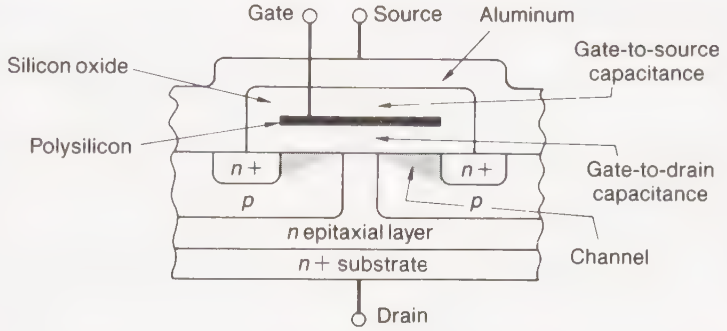
For detailed brochure, contact Pepperl+Fuchs, Inc. or your local representative.

Circle 402

TURN-ON SEQUENCE FOR BIPOLARS AND MOSFETs



Bipolar transistors turn on slowly because appreciable charge must first be supplied to the metallurgical base, then to a current-induced base, and finally to a remote base formed by the parasitic base-collector diode. Turn off, which is performed in the reverse order, also is slow. Power loss during these switching operations is high.



Power MOSFETs turn on and off quickly because little energy is required to form a conducting channel and to charge the gate-to-drain and gate-to-source capacitances. Power loss during these switching operations is low.

The gate voltage V_G reverse biases the gate/channel junction. Because the reverse-biased channel region is depleted of electrons (n-channel JFET), it does not conduct current flow. Thus, the width of the "conductive" channel is decreased and its resistance is increased.

Channel voltage comes from the drain to source voltage V_{ds}. Because the source is normally grounded, the channel voltage is greatest near the drain, causing the depletion region to be wider and the "conductive" channel narrower there. As V_{ds} is increased, the depletion region widens and the channel resistance increases. At pinchoff, the channel resistance reaches a maximum and the current flowing into the drain saturates.

MOSFETs: Metal-oxide semiconductor field-effect transistors have three or four terminals. A fourth terminal can provide a second connection to the gate, which can minimize gate-drain capacitance in high-frequency applications. Although several circuit symbols are used to denote MOSFETs, inward-pointing arrowheads always signify n-channel devices and outward-pointing arrowheads signify p-channel.

Three terminal MOSFETs have the same terminal names as JFETs; source, drain, and gate. Like the JFET, a voltage applied to the gate terminal controls MOSFET channel resistance. But the gate region is not a junction. It is a metal-oxide sandwich running the length of the channel surface. MOSFETs also differ in that their source and drain regions are junctions and not simply contacts.

Source and drain are shallow n-type regions in an n-channel MOSFET. The channel is p-type. With no bias applied to the gate, the resistance of the path between the source and drain is high and current does not flow. A positive voltage on the gate induces a buildup of electrons below the gate oxide. When the gate voltage is sufficiently large, the p-type channel is inverted to n-type material and it connects the n-type source and drain. As V_G increases, the inversion channel widens lowering the channel resistance.

Because little current flows into the gate — it is an insulator — MOSFETs consume the least amount of power of the three transistors. And, for the same reason, it has the highest input resistance. Input resistance typically is in excess of 10^{10} Ω, allowing one device to operate a large number of MOSFETs.

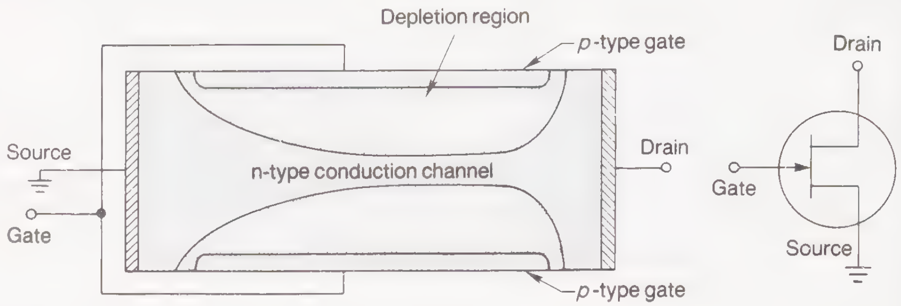
There are two types of MOSFETs, which differ in construction and in operation. One type is called a depletion-mode MOSFET and the other enhancement mode. A depletion-mode MOSFET conducts current without a gate bias. In an n-channel device, a thin n-type region exists under the oxide in the absence of an applied bias. It connects the source and drain allowing current flow. In fact, a negative voltage is required to drive the electrons out of (deplete) the region to increase channel resistance and reduce current flow.

In an enhancement-mode MOSFET there is no current conducted in the absence of a gate voltage. Without a gate bias, the channel under the gate is the opposite polarity of the source and drain. Increasing negative gate voltage to "drive more electrons out of the channel" has no effect. A positive voltage induces an n-channel and allows current to flow.

MOSFET devices must be protected from static electrical charges because excessive charges on the gate terminal can destroy the device. For example, the static charge generated on a person's body can weaken or break the gate oxide. Some MOSFETs incorporate internal protective diodes to combat static charges. Others are packaged with all leads shorted together with a metal ring that should not be removed until the device is permanently installed in the circuit.

MOSFETs are gaining on BJTs in terms of new applications. They are faster and require less drive power, and low-voltage versions exhibit less on-resistance. Also, prices of low-voltage

Channel resistance is controlled by a negative bias applied to the gate of an n-channel junction field-effect transistor. The gate voltage reverse biases the gate/channel junction causing depletion regions that constrict current flow. The circuit symbol of a JFET has an arrow pointing toward the gate in n-channel devices and away for p-channel.



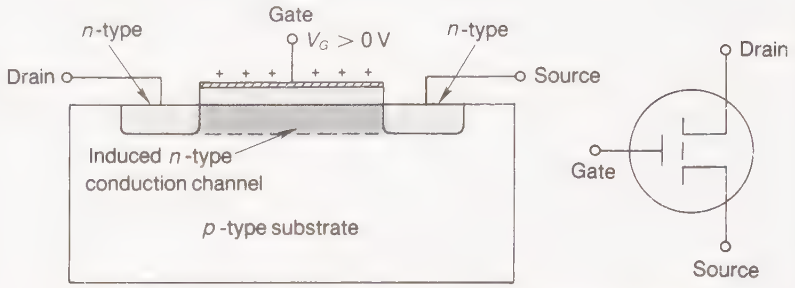
MOSFETs have dropped rapidly because of new designs and improved manufacturing techniques.

MOSFET manufacturers have cut product cost by increasing cell density. MOSFET chips contain a large number of identical cells connected in parallel. The first generation of power MOSFETs typically contained 500,000 cells/in.^{2}, but second-generation devices contain 800,000 cells. And third-generation MOSFETs have 1 million or more cells/in.^{2} Higher cell densities are advantageous because in devices rated at 100 V or less, on-resistance drops rapidly as cell density increases and channel length decreases.

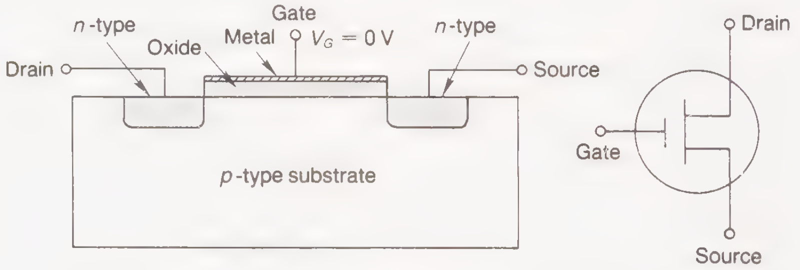
New fabrication techniques also provide faster fall times because of the smaller volume of material. Fall time for a new 50-V chip, for example, is 30 ns, down from the 90 ns typical for earlier devices. The small chips also turn on at about half the gate voltage. Input and output capacitance is lower by about the same amount.

Despite these advantages, MOSFETs have not been widely used in pulse-width-modulated (PWM) motor controls. A parasitic bipolar transistor, inherent in the device structure, made MOSFETs unreliable for this application. Unless each MOSFET was protected by a pair of diodes, the bipolar transistor could turn on unintentionally and destroy the MOSFET. The diodes, however, are costly and use precious chip space.

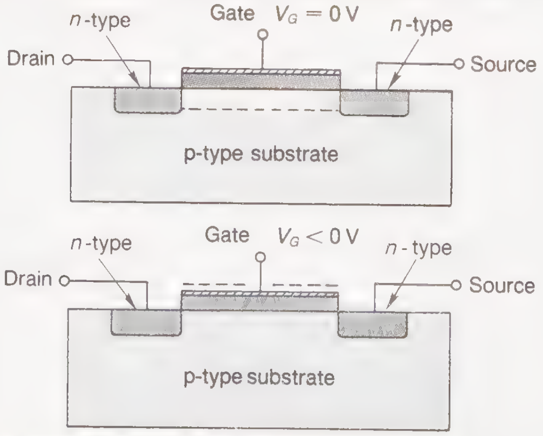
Excessive current in the body turns on the bipolar in forward or reverse mode depending on the direction of flow. The current may result from excessive dv/dt or di/dt. The reverse bias safe operating area (RBSOA) of the bipolar is much smaller than for the MOSFET. Thus, when a parasitic bipolar turns on and then attempts to turn off, it may fail if the voltage across it exceeds 50 or 60% of the MOSFET's rated value. Avalanching can also start a secondary breakdown where sufficient external energy is available.



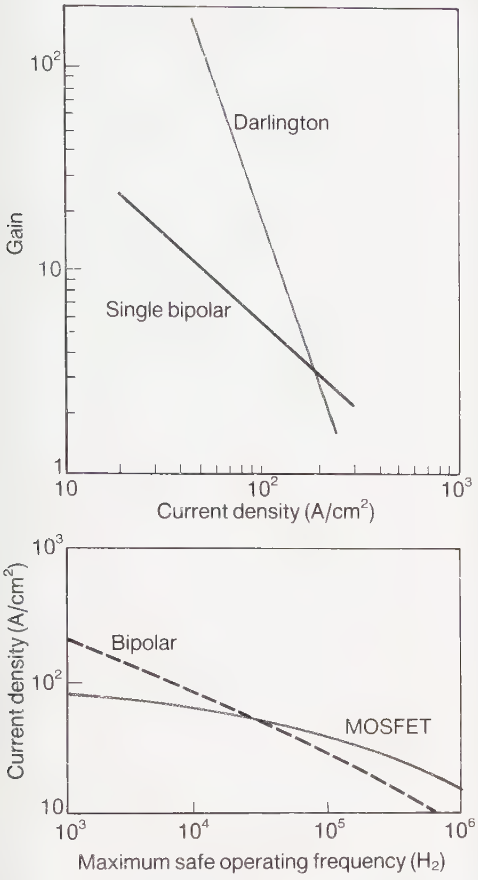
A positive gate bias induces an n-type conductive region in an n-channel enhancement MOSFET. A broken line in the circuit symbol indicates an enhancement device.



N-channel MOSFET has n-type source and drain regions in a p-type substrate. In an enhancement version, current does not conduct without gate bias. An outward arrow on a circuit symbol used for enhancement or depletion versions denotes an n-channel MOSFET.



An n-type conduction channel is present at zero gate bias in an n-channel depletion MOSFET. A negative gate bias depletes the channel of electrons and makes it nonconductive.



COMPARING BIPOLAR, DARLINGTON, AND MOSFET SWITCHING

Darlington gain at low current density is much higher than that of a comparable single bipolar transistor. This decreases as current density increases, but Darlington gain generally is higher than a single bipolar for all practical gain levels. The graph shows a 450 V_{CEO} Darlington compared with a single bipolar, each having 1-cm^2 conducting area.

Bipolar transistors usually withstand higher current density at low switching frequencies than MOSFETs because bipolars have lower losses in the "on" state. However, MOSFETs operate at higher current density than bipolars during high-frequency switching because MOSFETs have lower switching losses. An analysis indicates that, for a typical bipolar compared with a MOSFET having equal silicon area, the crossover frequency is between 10 and 20 kHz. Bipolars have almost a 2-to-1 advantage over MOSFETs at 1 kHz, but MOSFETs have approximately a 2-to-1 advantage over bipolar at 10 kHz.

Comparing MOSFETs and bipolars is straightforward where both are discrete components. But the differences are not obvious when the components are on ICs. Discrete power MOSFETs, for example, generally switch on and off faster and exhibit better safe operating areas than corresponding discrete bipolars. One reason is that discrete MOSFET fabrication uses 5 to 7-micron photolithography while discrete bipolars use 25 micron.

Power MOSFETs in ICs generally require less drive power than corresponding bipolars because of their high-impedance gate. MOSFETs require large voltage swings from full off to full on, a result of transconductance that is one or two orders of magnitude lower than bipolars. The swing is sometimes not compatible with IC control circuitry, and when switching at high frequency, slew rates sometimes exceed the capability of IC drive circuits. Appreciable drive power is required at high frequency, a result of high gate-to-drain capacitance.

Drive power requirements for bipolars sometimes exceeds 10% of the total power dissipation in the device. Darlington configurations require less drive power, but have higher on-resistance. Thus, the configuration generally is used only for high-voltage devices.

For 50 to 100-V devices, MOSFET on-resistance approximately equals that of bipolars. But for higher voltages, bipolar on-resistance is appreciably lower.

On-resistance increases with rising temperature for MOSFETs but decreases for bipolars. The negative coefficient for bipolars sometimes leads to device failure. The characteristic can be offset with complex, costly protective circuitry.

Above 200 V, the epitaxial channel material primarily determines on-resistance, thus, epi thickness must be increased. Resistance rises rapidly with increasing voltage. A result is that for a given current rating, high-voltage MOSFETs are much larger and, thus, more costly than low-voltage components. Nevertheless, MOSFETs sometimes compete with bipolar transistors in the 200 to 500-V range because drive circuits are less expensive.

Further, MOSFETs are now competing with BJTs in PWM motor-control applications. A newly designed power MOSFET virtually eliminates the parasitic bipolar transistor and allows the MOSFET to withstand large unclamped inductive loads. The design uses a continuous interdigitated metal source and gate instead of a closed-source cellular structure which eliminates overlap input capacitance and has large die size to achieve minimum on-resistance. The larger die size lowers the thermal resistance and reduces current density.

Presently, input capacitance limits switching speed of most MOSFETs to 200 kHz for applications such as motor control, switching power supplies, and PWM amplifiers. The lower input capacitance of the new devices will take the switching speeds up to 1 MHz at high voltage and current ratings. The consensus is that such devices will become the preferred power switch for applications demanding over 500-V withstand, and possibly for those up to 1,000 V or more.

IGBTs: Insulated-gate bipolar transistors (IGBT) combine the strengths of MOSFET and bipolar transistors. They have a MOS-like input with a BJT-like output. Voltage-controlled drive consumes little power because of the insulated gate. A large reverse blocking capability occurs because there is no body diode as in MOSFETs.

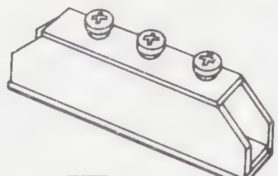
IGBT output capability is on par with power-bipolar Darlington pairs — 50 A and 1,000 V. But switching times are ten times faster because of a lack of junction effects at the input. Turnoff times range from 0.1 to 10 μs, for example. They also have a larger safe operating area. Further, current handling capability is increased by a low saturation voltage.

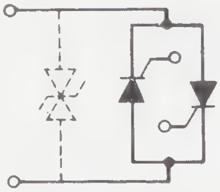
IGBT applications include motor controls and other industrial electronic systems. Although wide acceptance has been hampered by reports of slow fall times and overcurrent latching, several manufacturers claim to have overcome the latch problem. IGBT modules that handle 200 A and others that switch 1,200 V are planned.

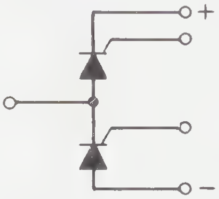
Thyristors: Thyristors have turn-on characteristics that can be controlled by externally applied voltage or current. These devices generally consist of interconnected layers of *p* and *n*-type semiconductor material.

Silicon-controlled rectifier (SCR): These are sometimes called reverse-blocking thyristors and have three terminals: the anode, cathode,

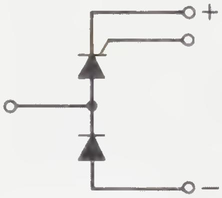
HYBRID SWITCHES



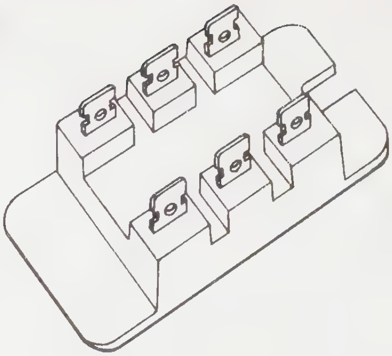

AC SWITCH

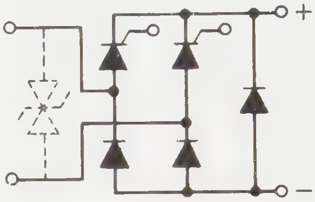


SCR DOUBLER

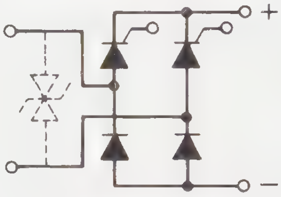


SCR DIODE DOUBLER





SCR BRIDGE WITH FREE-WHEELING DIODE



SCR DIODE BRIDGE

and gate. With a small forward voltage applied between the anode and cathode, the SCR is normally off and conducts no current (high-resistance state). If forward voltage increases sufficiently, the SCR begins to conduct. SCR voltage at the conduction point is called the breakover voltage. A signal applied to the gate terminal controls the level of breakover voltage. The higher the gate current, the lower the breakover voltage.

A gate signal need last from a few microseconds to milliseconds to fire an SCR into the forward-conducting state. Once it fires, the gate signal has no effect. The reverse characteristics of the SCR resemble those of a conventional reverse-biased diode. SCRs must be turned off by interrupting the anode current or reducing it below a minimum value called the holding current I_H. When gate current is zero, the minimum holding current is often referred to as the latching current I_L.

Gate turn-off switch: A gate turn-off switch, also known as a gate-controlled switch (GCS) or gate turn-off thyristor (GTO), is similar to an SCR but can be turned off by a negative signal on the gate terminal. GTOs generally handle much lower currents than SCRs.

GTOs have many characteristics of SCRs and transistors and in some ways are superior to both for power switching applications. GTOs switch dc current without the auxiliary components that SCRs require, resulting in reduced cost and lower electrical and electromagnetic noise. Also, GTOs latch on or off with a single pulse.

Despite their advantages, GTOs are not as widely used as once seemed possible. Their low use is probably because peak current that could be reliably turned off in early GTOs is limited to relatively low values. The limit is imposed by current filaments that produce localized hot spots during turn off.

Newer GTOs, however, turn off much higher current than previous models. Higher peak-controllable ratings are obtained with new shorted-anode structure, precise doping, and finely interdigitated geometry. The new GTOs, moreover, switch faster than previous versions, exhibit higher ratios of peak-to-average current, and greater on-state gain. Also, peak voltage ratings are higher than those for bipolars and Darlingtons.

GTOs generally cannot be turned off successfully when conducting current in the range between the maximum turn-off rating and the maximum surge rating. However, properly selected fuses may protect new devices from damage due to current in this range.

GTOs are similar to SCRs in that both are four-layer devices. However, the average current rating of GTOs, due to an interdigitated construction, is appreciably lower than that for SCRs of corresponding size.

Average current ratings for GTOs generally are quite close to those for Darlingtons of identical dimensions because similar interdigitation techniques are used for both. But GTOs generally are capable of turning off higher current because Darlingtons go out of saturation at high levels of current.

Silicon-controlled switch (SCS): SCSs are also called tetrode thyristors. They are similar to SCRs having two gate terminals, an anode gate, and a cathode gate.

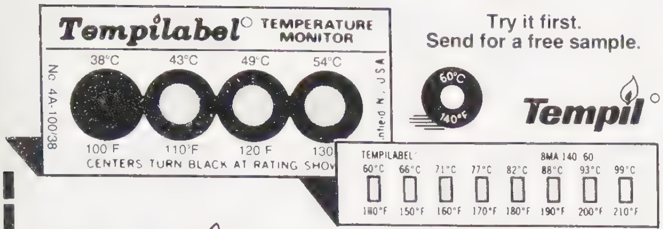
The two gates can be used in several ways. Putting a negative signal on the anode gate fires the SCS so that the device acts like a complementary SCR (conducting a positive current with a negative trigger). If the SCS is turned on with the cathode gate signal like a conventional SCR, a sufficiently positive signal on the anode gate will subsequently turn it off. A positive signal applied to both gates simultaneously turns the SCS on faster than an equivalent SCR. The SCS can also be turned off like a gate-controlled switch by applying a negative signal on the cathode.

Bilateral triode (triac): Triacs can withstand high current and are often used to control ac power. They are similar to SCRs, but capable of conducting current in two directions. With a small forward voltage applied between the anode and cathode, a triac is normally off and conducts no current. If forward voltage increases sufficiently, the triac begins to conduct. A positive voltage applied to the gate terminal controls conduction threshold. The higher the gate signal, the lower the triac voltage when conduction occurs. Triacs operate similarly for current flowing in the opposite direction. In this case, gate-signal polarity must be reversed; the more negative the gate signal, the lower the conduction point.

Unijunction transistor (UJT): Unijunction transistors have three terminals called the emitter, base 1, and base 2. The emitter material is p-type semiconductor and the base material is n-type. In complementary UJTs, base material is p-type and emitter n-type.

A signal applied to the UJT emitter terminal controls resistance between the base terminals. With no emitter signal, resistance between base 1 and base 2 is high and very little current flows. As the emitter voltage increases, the resistance between the base terminals remains high until emitter voltage reaches a point called the peak voltage V_p. At this point, resistance between the base terminals starts to decrease as

How to put a low cost temperature gauge on everything.


Tempilabel° TEMPERATURE MONITOR
38°C 43°C 49°C 54°C
No 4A-100/38
100°F 110°F 120 F 130
CENTERS TURN BLACK AT RATING SHOW
Printed N. USA
60°C 140°F
TEMPILABEL
8MA 140 60
60°C 66°C 71°C 77°C 82°C 88°C 93°C 99°C
140°F 150°F 160°F 170°F 180°F 190°F 200°F 210°F

Try it first.
Send for a free sample.

Tempil°

Tempilabel° TEMPERATURE INDICATING LABELS

The center spot on a Tempilabel° turns black when the surface to which it is affixed reaches the specified temperature (from 100° to 600°F). Tempilabels° are available with single spots, or with multiple spots for monitoring safe operating temperatures. They provide permanent temperature records, and are thus useful in designing components and selecting materials. If you are not now using Tempilabels°, fill in the coupon. We'll be glad to send you a sample that you can try in your own plant or laboratory.

Tempil Division, Big Three Industries, Inc. 2901 Hamilton Blvd.,
So. Plainfield, NJ 07080 • 908-757-8300 • Fax: 908-757-9273

☐ Send sample of Tempilabel° For use at ________°

Name ______________________ Tel ______________________

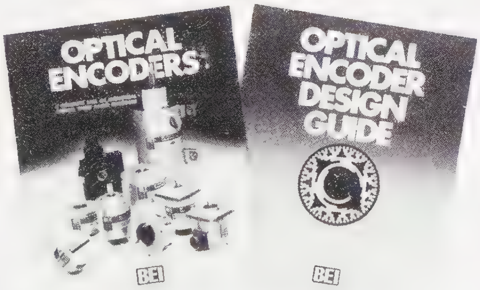
Company ______________________

Street ______________________

City __________ State __________ Zip __________

Circle 403

ENCODER 2 FOR 1



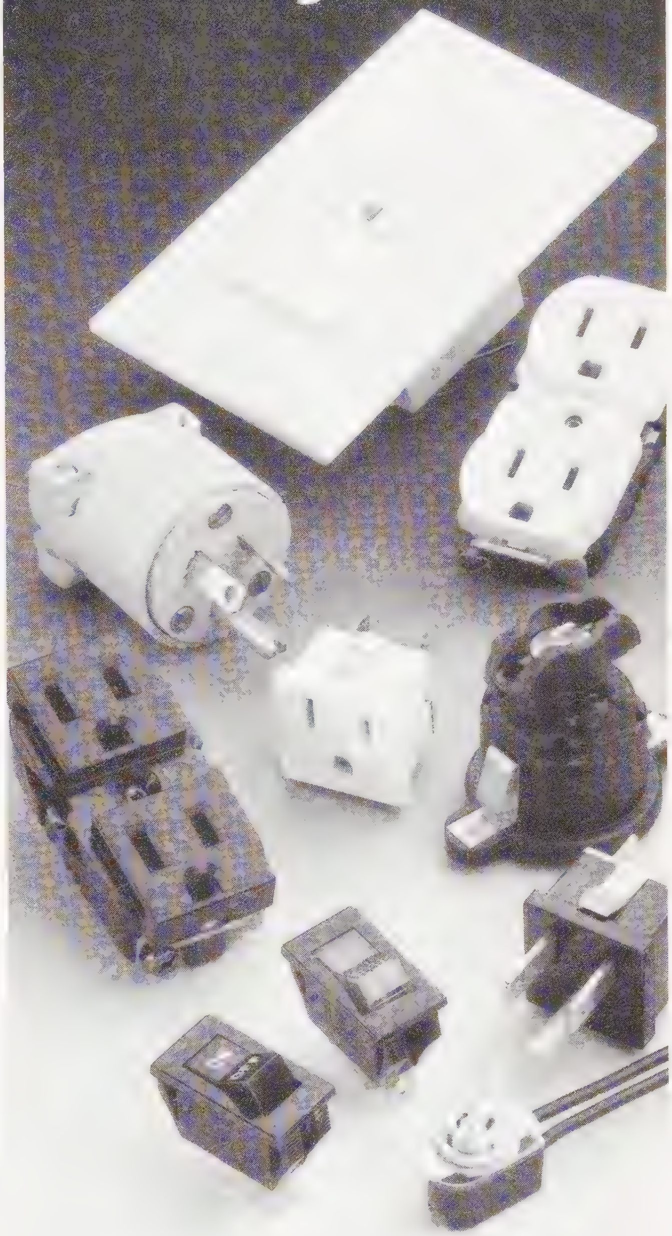
We'll send you two excellent encoder brochures for one request. The 16-page Design Guide details everything from how encoders work to how to configure encoders for specific applications. The 20-page Specifying Guide details the specs on our basic encoders, including optional configurations, notes and performance tables. All it takes is one request.

Call or write BEI at 7230 Hollister Ave., Goleta, CA 93117, 805/968-0782; 800/350-ASAP(2727); FAX 805/968-3154

BEI BEI MOTION SYSTEMS COMPANY
Industrial Encoder Division

Circle 404

Ready when you are!



We make over 2500 electrical devices to fit just about any application, anytime.

From canopy switches, toggle and rocker switches and circuit breaker switches to caps, connectors, receptacles and grounding outlets; over seventy years of manufacturing experience go into every Eagle wiring device.

Our ground fault circuit interrupters are individually computer tested to insure perfect performance.

Our Attachon sockets feature a twist cap that locks wire into place permanently. And very quickly.

You can count on Eagle to deliver what you need when you need it. Send for our current catalog today or write:

EAGLE *Competing to be your first choice*

Mr. J. Mannarino, National Sales Manager (O.E.M. Dept.)
Eagle Electric Mfg. Co., Inc., 45-31 Court Square
Long Island City, NY 11101, (718) 937-8000 Ext. 2079

Circle 405

current flowing into the emitter terminal increases. Emitter voltage decreases as emitter current increases until a voltage valley point V_v. After the valley point, increasing emitter currents cause an increase in emitter voltage.

Unijunction transistors can be used as negative resistors when operated between V_p and V_v. This characteristic and a low firing current make them useful in oscillator and timing circuit, and triggering SCRs.

Diacs: Diacs consist of ac trigger diodes and bilateral diodes. Each has two terminals and behaves the same for current flow in either direction. When a small voltage of either polarity is applied across the diac, little current flows. Diac resistance remains high until applied voltage reaches a breakdown voltage point. At this point, diac resistance drops and high current begins to flow. Since this action occurs in both directions of current flow, the device is sometimes called an ac switch. It is often used for triggering triacs.

Four-layer diode: Four-layer diodes are also called Shockley diodes and have two terminals. When a small forward voltage is applied across the four-layer diode, little current flows and the diode resistance is high. Resistance remains high until the forward voltage increases to a switch point V_s. Then high current begins to flow and the voltage drops. Once the diode is forward conducting, it can be turned off by reducing the current or voltage below a holding value.

In the forward direction, current encounters two forward-biased junctions and one reverse-biased junction with a low breakdown voltage. For voltages applied in the opposite direction, the diode blocks current and behaves like a conventional reverse-biased diode. In this direction, current encounters one forward-biased junction and two reverse-biased junctions, each with large breakdown voltage.

MOS-controlled thyristor: A new type of power switch has been recently introduced by General Electric Corp., Solid State Div., now part of Harris Semiconductor Corp. The MOS-controlled thyristor (MCT) adds speed to power switching. It is similar to the gate turn-off (GTO) thyristor, but much less drive power is needed to turn off the MCT because little current flows into the gate. MCTs can handle 100 A at 1,000 V with turn off times under 2 μs and turn-on times of 200 ns. In addition, it also has a low holding voltage in the on state.

Power switching

Power control modules are circuits comprising devices such as silicon-controlled rectifiers, triacs, power transistors, and power rectifier diodes. These circuits can function as pulse-width modulators, or as switches to provide a variable power level to a specified load.

Power modulators electronically control the ratio of on-time to total device operating time (duty cycle or firing angle). They have greater adaptability to control modes, are more compact, have longer life, and are more efficient than older methods.

Essentially, ac power control modules consist of trigger circuits that control load current flow through a power-switching thyristor, usually a triac or SCR. Two switching methods are often used to control ac power: phase control and zero-voltage switching.

Phase-control switching: In phase control, continuously variable power is obtained by controlling the conduction period of a thyristor supplying the load. SCRs can be used singly for half-wave power control, or in combination for full-wave control. For partial range control of loads that are insensitive to nonsymmetrical waveforms, simple circuits for SCR/di-

MICROPROCESSOR-BASED
TEMPERATURE CONTROLLER

MODEL 5C6-323
ONLY $98.00
at 250 pieces

*PROPORTIONAL AND INTEGRAL CONTROL MODE
*STANDARD DUAL SENSOR OPTION
*LED DIGITAL READOUT IN EITHER C. OR F.
*SET TEMPERATURE OR EITHER SENSOR DISPLAYED
*OPEN BOARD CONSTRUCTION
*MINIMAL INSTALLATION TIME
*STANDARD TEMPERATURE RANGE IS 25° TO 120°C.
*CUSTOMIZED TEMPERATURE RANGES AVAILABLE
*AND MANY MORE ADDITIONAL FEATURES

*REQUEST COMPLETE LITERATURE

OVEN INDUSTRIES, INC.
P.O. BOX 290, MECHANICSBURG, PA 17055
TEL: (717) 766-0721 FAX: (717) 766-4786

Circle 406

LOAD CELLS
FORCE SENSORS
TORQUE SENSORS

FREE NEW CATALOG!

Catalog Includes:
• Gram Sensors • Mini Load Cells • Low Profile Load Cells • Economical Tension Load Links • Torque Transducers/Sensors • Transducer Indicators • Multichannel Strain Gage/Transducer Signal Conditioning • Special OEM Sensors

Transducer Techniques
(714) 676-3965
FAX (714) 676-1200
43178 Business Park Drive, B-101 • Temecula, CA 92390

Circle 407

ode combinations can be used. However, commercially available modules are designed to produce symmetrical, half-wave, or full-wave voltages. For full-wave operation, the circuits are usually designed for use with a triac.

When a triac is triggered into conduction in a phase-controlled circuit, voltage is applied instantaneously to the load, the value of which depends upon the firing angle. The sudden surge of load current generates RFI in the circuit which is both propagated through space and reflected back into the power line. The closer the trigger point is to the peak of the sine wave, the greater the level of RFI generated. To minimize this condition, phase-controlled modules can be supplied with RFI filter networks consisting of resistors, capacitors, and inductances. The level of power determines the bulk and cost of the filter network required.

Zero-voltage switching: Zero-voltage switching is a form of on-off control that delivers power to a load in a series of full-cycle bursts. Thyristor turn-on and turn off occur at, or very near the zero-load current point of the ac cycle. Thus, filtering is not normally required for the small amount of RFI generated. But zero-crossing trigger circuits are more complicated than comparable phase-controlled circuits.

Features include differential input, internal power supply for external-component biasing, and protection circuits for opened or shorted sensors. Others are available with extended input compatibility for sensor impedances, internal protection against half cycling, bridge sensing with adjustable-hysteresis set points, operation from an ac or dc supply, and proportional control for increased accuracy.

Proportional control is used when simple on-off application of power to the load would result in unwanted overshoots (from set point) of the controlled variable. For example, in simple on-off control of a space heater, full power is applied to the heating element until the ambient temperature reaches set-point temperature. However, the system inertia usually causes additional ambient-temperature increase until the heater element cools to the temperature of the environment.

Hybrids: Power circuit modules containing several power semiconductor switching devices can reshape ac power into other required forms and often have current ratings from 30 to 50 A. The semiconductor elements in these devices are usually SCRs or triacs and are glass passivated and mounted on a copper-clad ceramic substrate to efficiently conduct heat to the ambient. Common configurations include single-phase half-wave bridges that often contain a freewheeling diode for inductive loads, switches for single and three-phase ac switching applications, and SCR doubles for single and three-phase bridges.

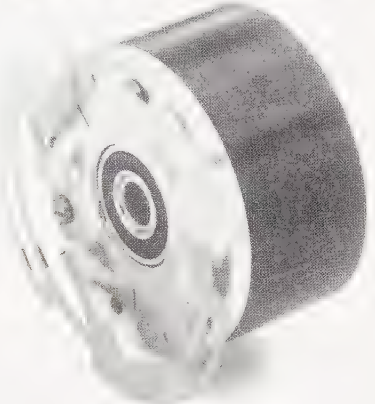
Power ICs

Despite a slow start, smart power is gaining momentum in automotive, industrial, and data-processing applications. In these environments, power ICs typically drive motors, solenoids, and lamps. They also provide power supply and interface functions.

Smart power ICs are the interface between digital control logic and high-power loads. More specifically, the Joint Electronic Device Engineering Council (Jedec) defines them as monolithic or hybrid semiconductor devices that provide signal conditioning and power control, along with fault management and diagnostics. They have a peak output rating of at least 1 A and a voltage rating of at least 30 V for both supply and load.

RENCO RHS Series Incremental, Hollow Shaft Encoder

Motion Control Made Simple.



- Flexible mounting plate accommodates large axial shaft movement
- Resolutions to 5000 CPR
- Single LED illumination source
- Differential sensor array
- No electro-optical alignment required
- 24 Hour shipment on many standard configurations

Renco RHS Series encoders are available in 2.1 in. and 2.5 in. dia. packages with features for a wide range of speed and position control applications. A myriad of mechanical interfaces are offered including shaft ID's and mounting plates. RHS Series encoders "drop" onto any shaft with little or no tooling, providing an extensive range of output characteristics options. A commutation option is also available for brushless motor applications

☎ Call 1-800-888-5007 for our Immediate FAX Facts.

RENCO

Renco Encoders 26 Coromar Drive, Goleta, CA 93117-3094 • FAX (805) 685-7965

Circle 408

Power ICs range from simple to complex. Simpler ones may include only a few level-shifting and drive circuits to translate microprocessor signals into voltage and current sufficient to energize a load. Display drivers, for example, fall into this category. Though displays are capacitive in nature, and often solid state, they still require drive voltages beyond what logic circuits can provide.

At the other extreme, power ICs may include load monitoring, diagnostic functions, self-protection, and information feedback to the microprocessor. A typical application for a full-featured power IC is in automotive multiplexing, where distributed smart-power modules can control lights, windows, seats, and air conditioning, reporting to microcontrollers over a two-wire bus.

More than a set of specifications, "smart power" is a new approach to managing electromechanical and other high-voltage loads, using multifunctional components. The three primary functions of smart power are power control, sensing/protection, and logic interfacing.

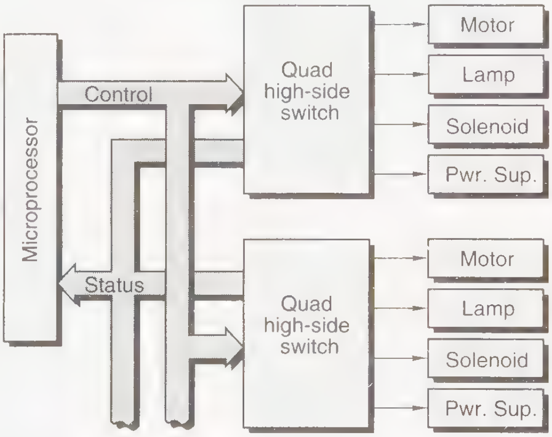
Power control is provided by high-power devices and their drive circuits. A variety of power devices are used, including bipolar and MOSFET transistors, insulated-gate bipolar transistors (IGBTs), and MOS-controlled thyristors. MOS-gated devices increasingly are favored. The ability to switch both high voltage and high current is the trademark of smart-power technology.

Drive circuits, on the other hand, are typically made using a high-voltage CMOS process. Operating at up to 30 V, they provide sufficient gate voltage to control the power devices. To accommodate totem-pole configurations, where two or more devices are connected in series, drive circuits must also be capable of level shifting to higher voltages.

Sensing and protection is also important. In addition to detecting excessive current, voltage, and temperature, many power ICs also sense when a load has been disconnected and when load voltage falls below a safe level. Under-voltage warnings can prevent extreme power dissipation during load start-up by properly biasing the power devices. Current sensing is done with minimum power loss by partitioning a few cells from the power device and feeding the small current to the control circuit.

QUAD SWITCHES AT WORK

Banks of high-side switches allow a single microprocessor to control and monitor dozens of loads over two-wire buses. In industrial and automotive applications, these switches can provide thermal warning, power limiting, and other forms of load protection independent of the main computer.



Feedback loops typically contain high-frequency bipolar transistors. Fast response is critical for a benign shutdown because system current increases rapidly during a fault. To maintain speed and accuracy, this portion of the chip uses high-performance analog circuits.

Interface functions are typically provided by high-density CMOS logic circuits. These circuits perform encode and decode operations to communicate with microprocessors and other logic components. Not only do smart-power ICs respond to microcontrollers, they also send messages regarding operating status, load monitoring, and diagnostics. Messages may include over-temperature shutdown requests and no-load or short-circuit warnings.

Intelligent power is expected to have the greatest impact on applications where solid-state switches are already used. Here, loads range from 10 to 10,000 V and current from a few milliamps to several hundred amperes. On one end of the spectrum are display drives that generate less than 0.1 A at 100 V or so. Because displays are typically linked to microprocessors, these applications are ideal for power ICs.

At the high end are vehicle traction and high-voltage dc (HVDC) transmission systems, where voltage requirements exceed 1,000 V and switching currents are several hundred amperes. Novel MOS-bipolar devices under development could enable smart power to penetrate even these applications. Meanwhile, intense efforts are being directed to motor control, factory automation and robotics, computer power supplies, and automotive electronics.

Another area where smart power is thriving is in disk drives. Spindle motors that rotate the hard disk must maintain constant rpm, while voice-coil motors that position read/write heads must be accurate and fast.

One of the biggest challenges to integrating various devices on the same chip is to isolate low-power circuits. Electric fields from high-power switches, for example, can interfere with CMOS logic operation. Several isolation methods are being used with trade-offs in cost, chip size, and voltage range.

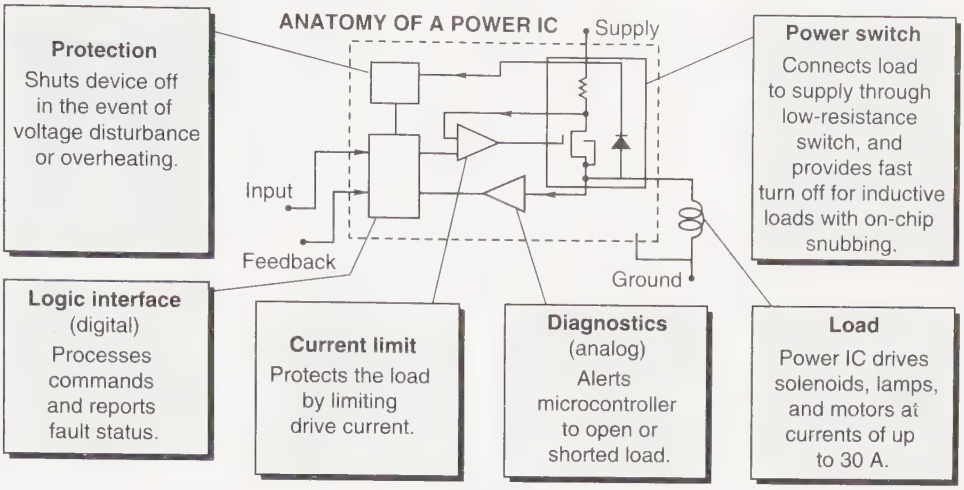
Most smart-power chips employ junction isolation. Reverse-biased *p-n* junctions surround logic gates, electrically separating them from the power stage. Isolation junctions can be formed during standard masking steps. Drawbacks, however, include wasted silicon because of the junction area and the need for thick epitaxial layers, especially at higher voltages.

Another approach is called dielectric isolation. Dielectric wells isolate power devices from the logic section, blocking high-voltage fields of up to 600 V. The process is expensive, however, because it often requires mechanical back-lapping and additional mask steps.

If the cost of dielectric isolation comes down, it is likely to be the method of choice for most power ICs. For starters, it offers the best isolation and highest circuit density. It also simplifies chip design by eliminating parasitics, and would allow IGBTs and MOS-controlled thyristors to be integrated on the same die with digital control circuits.

Another challenge to power IC designers is to prevent signals from interfering with one another. Signal lines from precision analog, digital, and high-power circuits often come into proximity or crossover. As a result, energy induced by high currents and rapidly changing voltages can be coupled into low-current low-voltage conductors and degrade device operation.

According to Texas Instruments, a power IC such as a high-side driver is more than just a current switch. The component also contains logic and protection circuits, diagnostics, and current limiters. Although the power switch shown is a MOS device, bipolar npn transistors can also be used. Feedback current is taken from a few sensing cells, represented by a low-value resistor.



Protection
Shuts device off in the event of voltage disturbance or overheating.

Logic interface (digital)
Processes commands and reports fault status.

Current limit
Protects the load by limiting drive current.

Diagnostics (analog)
Alerts microcontroller to open or shorted load.

Power switch
Connects load to supply through low-resistance switch, and provides fast turn off for inductive loads with on-chip snubbing.

Load
Power IC drives solenoids, lamps, and motors at currents of up to 30 A.

WHAT'S NEW IN SEMICONDUCTORS

Since the invention of bipolar transistors, designers have pushed semiconductor suppliers to increase the amount of power these devices can switch. Some of the biggest leaps in current and voltage capability, however, have come in the last three years. By 1990, thyristors made from 100-mm-diameter wafers were commercially available to block 6,5000 V in the off state and conduct over 2,000 A in the on state.

Like most advances in semiconductor drive technology, recent progress in bipolars is based on new material and process techniques. Each thyristor is made from an entire silicon wafer, and device ratings are determined chiefly by material properties — resistivity, wafer diameter, and defect density — which have improved significantly in the last few years.

Another reason for the progress is a highly uniform doping process that allows optimum junction profiles. Called neutron transmutation doping, the technique converts silicon isotopes to phosphorus by the absorption of thermal neutrons. Conventional doping methods require phosphorus atoms to diffuse into place, a process which is more difficult to control.

Over the years, the technology to make power bipolar devices fell behind that of integrated circuits. Design rules were maintained to support high power: line widths persisted in the range of tens of mils and junction depths from tens to hundreds of microns. Consequently, power ICs were infeasible with conventional bipolar technology. But the introduction of power MOSFETs in the 1970s and MOS/bipolar devices in the 1980s changes everything.

Power MOSFETs are superior to bipolar transistors in terms of input impedance, switching speed, safe-operating area, and the ease with which they can be paralleled. These qualities make them attractive for applications such as computer power supplies and automotive electronics, where blocking voltages are below 200 V.

One of the most important measures of a power MOSFET is its current rating, which is determined by the resistance of the drive. Resistance can be reduced by making the channel length shorter, an acceptable trade-off for devices with blocking voltages below 100 V. Another way to reduce resistance is to distribute current evenly across the channel. This is done by shrinking the polysilicon gate, using VLSI technology.

As MOSFETs approach the theoretical limit for 50-V silicon devices, 0.15 $m\Omega/cm^2$, further improvements will require the development of other semiconductor materials. One promising new material for power MOSFETs is silicon carbide. Replacing silicon with silicon carbide can reduce specific on-resistance by a factor of 100 or more.

Another way to beat MOSFET current limits is to use MOS/bipolar devices or IGBTs (insulated-gate bipolar transistors). Like MOSFETs, these devices feature high input impedance and fast switching speed. Typical turn-off times range from 0.1 to 10 μs. In contrast, however, IGBTs can switch 10 times more current per unit area. Applications include medium-frequency circuits with blocking voltages over 200 V, such as adjustable-speed motor drives, appliance controls, and robotic/numeric controls.

To isolate signal conductors, chip designers are increasingly turning to a two-level metal process. A thin metal layer connects analog and digital circuits, while a thick metal is used for power devices. The two layers are separated by a dielectric such as silicon dioxide. High-voltage crossovers and gate electrodes are made from polysilicon, a heavily doped layer of polycrystalline silicon that conducts current.

For applications where blocking voltage must exceed 100 V, however, new problems come into play. The reason is that standard power devices (vertical transistors) must be made excessively large to limit on-resistance. Instead of vertically integrated devices, designers are turning to lateral transistors for high-voltage applications. Formed in thin epitaxial layers, these devices can reach breakdown voltages of up to 1,200 V. The process, called reduced surface electric field or Resurf, has found a niche in high-voltage power ICs.

Power op amps: Power operational amplifiers (POPs) are becoming increasingly common in control circuitry. Their primary advantages over conventional amplifiers are reduced part counts, increased reliability, and simplified design. And while the individual components of a power op amp may cost more than alternatives, total cost, including design time, logistics, and production costs, may be less.

There are other advantages as well. When used as linear motor drivers, operational amplifiers produce lower electrical noise than their fast-switching digital counterparts.

Some devices can dissipate 500 W continually and deliver 30 A of current. The power and current handling capability is primarily the result of new packaging and protection techniques.

POP designers give close consideration to thermal characteristics. Manufacturers use copper-alloy packages and lead frames over steel because of its superior thermal conductivity. Copper conducts heat over five times faster than steel. To isolate localized substrate heating, and prevent cracking, multiple substrates are used. New soldering processes eliminate voids under the die and substrate, allowing higher safe operating areas (SOA).

Some op amps incorporate a voltage-current limiter circuit to protect the amplifier from SOA damage such as a short to ground. The limiter senses both output current and output voltage, and increases current limit value as output voltage approaches supply voltage. The circuit is activated by connecting a programming resistor.

The alternative to power op amps in most applications is to build comparable circuits with discrete power transistors. The discrete approach has often been less expensive in applications that do not demand high performance. Typically, discrete designs must use class C power outputs (where output transistors are off for much more than half the cycle) rather than class B or AB complementary output used on hybrids.

One reason discrete designs are often built class C is because their outputs cannot be thermally matched sufficiently to obtain a class B output. The problem is that the voltage needed to drive a given amount of current through a transistor drops appreciably with temperature. Thermal tracking circuits that compensate for the effect are difficult to construct with discrete components because the circuits must precisely register the temperature of the base-emitter junction of the power transistor. On the other hand, hybrid circuits (and monolithic devices) can provide tracking more easily because of the close proximity of components.

Discrete power amps based on class C operation commonly use a feedback circuit to obtain adequate response. Manufacturers say that such designs are often acceptable where loop response time is less than 1 ms and where amplified signals are 1 kHz and lower. But such discrete designs may be difficult to stabilize at higher speeds. Feedback in class C designs is nonlinear with rapid changes in stage gain as the circuit goes from threshold to full on. Because of such difficulties, discrete power circuits may produce greatly distorted outputs when operating at frequencies of around 10 kHz.

Many POP designs ultimately drive some type of dc motor. Manufacturers warn of several considerations that must be taken into account for such circuits, particularly back electromotive force. When the motor suddenly stops or reverses, a large voltage develops across the amplifier output stage. The output transistor also current limits, and this combination must be checked against the SOA.

Other inductive loads such as lead wires or coils can also drive a POP out of its SOA. To guard against transients, some amplifiers have built-in protection diodes that clip flyback voltages greater than V_s. In other designs, external diodes must be used.

Large capacitive loads can cause POPs to oscillate. Usually, critical capacitance depends on the amount of feedback. The lower the gain, the lower the capacitance that can start oscillations. Op amp manufacturers can suggest ways to deal with capacitive loads and prevent ringing.

Because POPs operate at high currents, manufacturers have issued precautions for prototype designs.

- When a circuit is powered up for the first time, power supplies should be set to the minimum operating level indicated on the data sheet.
- Current limit levels should be set by current limiting resistors, not the lab power supply. A low current setting on the supply does not always provide surge protection from the filter capacitors. Current limiting resistors ensure operation in the SOA, and prevent breakdown of the bipolar output stages.
- Once basic circuit operation is verified, the current limit can be raised. After the worst case operating conditions have been checked, supply voltages can be increased.
- Improper grounding also causes POP performance problems, because large output currents can cause ground loops. In general, loops can be avoided by returning grounds (for load, output compensation, and low-level signals) separately to the same point. Improper grounding of test equipment also causes difficulties. A common recommendation is to eliminate any direct ground connection between the signal generator and oscilloscope timing input.
- Although a POP may be rated to dissipate 90 W continuously, it cannot do so unless properly mounted on the heat sink. One manufacturer reports that customers sometimes drill a single hole encompassing both pins in the heat sink to mount a TO-3 package. Because most heat comes from inside the pin circle, a long thermal path and poor operation result.

Relay and switch technology

For maximum power transfer, switch contacts should have zero resistance. Unfortunately, clean contact resistance is directly proportional to volume resistivity of the contact material and inversely proportional to the contact area. This resistance typically is on the order of a few milliohms for pure metal-to-metal contact. But certain phenomena that occur during switching can deteriorate the interface and greatly increase contact resistance. The degree to which these phenomena affect contact resistance depends on contact materials, operating environment, contact pressure, and the type and magnitude of current switched.

Switch contacts

Asperities: Mass-produced switch contacts have an rms roughness ranging from 0.5 to 1 × 10^6 in. These "smooth" surfaces, in reality, comprise microscopic peaks and valleys. As a re-

Contact materials

Metal	Melting point (°C)	Resistivity (μ-cm)	Temperature coefficient of resistivity (per °C)	Thermal conductivity (cal-cm sec-° C-cm^2)	Oxidation resistance	Arcing effects
Gold	1,063	2.42	0.0034	0.71	Excellent	Pits and transfers at high current and voltage
Molybdenum	2,625	5.7	0.0033	0.35	Good	Pits and transfers at high current and voltage
Palladium	1,552	11	0.0038	0.11	Fair	Resists arc erosion
Platinum	1,773	10.60	0.0030	0.17	Very good	Resists arc erosion
Silver	960	1.63	0.0038	1.01	Excellent	Pits and transfers at high current and voltage
Tungsten	3,410	5.52	0.0045	0.48	Good	Resists arc erosion

KEYSWITCH AND MEMBRANE KEYPAD CONSTRUCTION

Various keyswitch mechanisms are available, but conductive-elastomer and membrane keyswitches are together the most widely used switch types. These switches are inexpensive and reliable because of few moving parts. They are also inherently rugged because of their underlying materials. Silicone elastomers, polyesters, and polycarbonates all resist dust, water, chemicals, and solvents.

Conductive-silicone elastomer switches are made from silicone rubber. They are the newest of the switch technologies. Conductive-elastomer switch lifetimes are typically between 20 and 30 million actuations. A large selection of keypad layouts are available off-the-shelf, many having full-travel keys.

Silicone elastomers can be compounded to be insulative or conductive. Carbon-filled rubber is conductive and is used as a shorting tip on elastomeric switches. Insulative silicone, on the other hand, provides snap-spring action for tactile response and is also used as a boot to seal the switches.

The contact resistance of carbon-filled elastomer switches is typically around 200 Ω. Thus, they are more suited for low current or power. Silver-filled elastomer shorting tips provide lower contact resistance, but the cost per switch nearly doubles.

Membrane keypads consist of three thin insulating materials. A flexible film forms the front layer on which is deposited movable contacts. Stationary contacts are on a rear layer. Between these two layers is an insulator with openings cut at contact locations. Pressure applied to the front sheet in a cutout area flexes the film toward the bottom sheet and closes the contact. The movement is about 0.007 in. and requires an operating force of 2 to 10 oz.

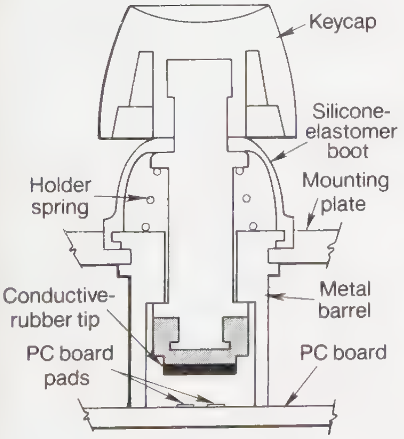
Membrane switch panels can be flexible or rigid. All three members of a flexible panel are made of flexible materials. External connections to a flexible panel are made through a flexible tail, on which the necessary conductive tracks are deposited. Rigid panels are constructed with a circuit board serving as the rear layer. External connections are made through terminal pins, solder pads, or ribbon connectors.

Flexible panels must be mounted on a flat rigid surface and are generally supplied with an adhesive lining so that the panel can be bonded to a support. Rigid panels are generally mechanically fastened to an enclosure.

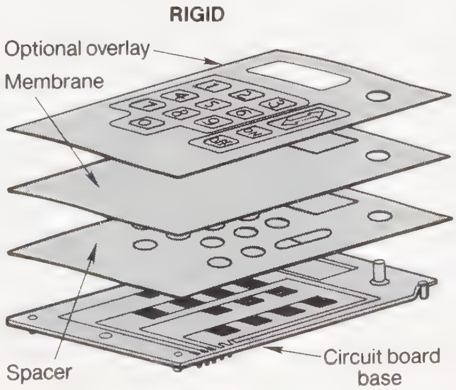
Contact designations, symbols, or other graphics are printed, lithographed, or screened on the front panel or on overlays of other flexible materials.

Full-travel membrane keyboards often use a moving contact layer with etched copper foil. This layer contacts a stationary layer containing conductive traces.

continued on page 542



Conductive-elastomer keyswitch systems are one of the newer switch technologies. Rugged materials and fewer moving parts provide a reliable low-cost keyswitch.



A rigid membrane switch panel has a printed-circuit board base with fixed terminals, whereas a flexible panel has a flexible base and an integral flexible tail for terminals. The flexible panel is generally less costly but requires a flat, rigid surface for mounting.

sult, two mating contacts touch only at the surface peaks or asperities. Contact force between the two surfaces plastically flattens these asperities until the sum of the reaction forces equals the applied contact force. Thus, initial contact area increases and resistance decreases. Still, final contact area is much smaller than apparent contact area.

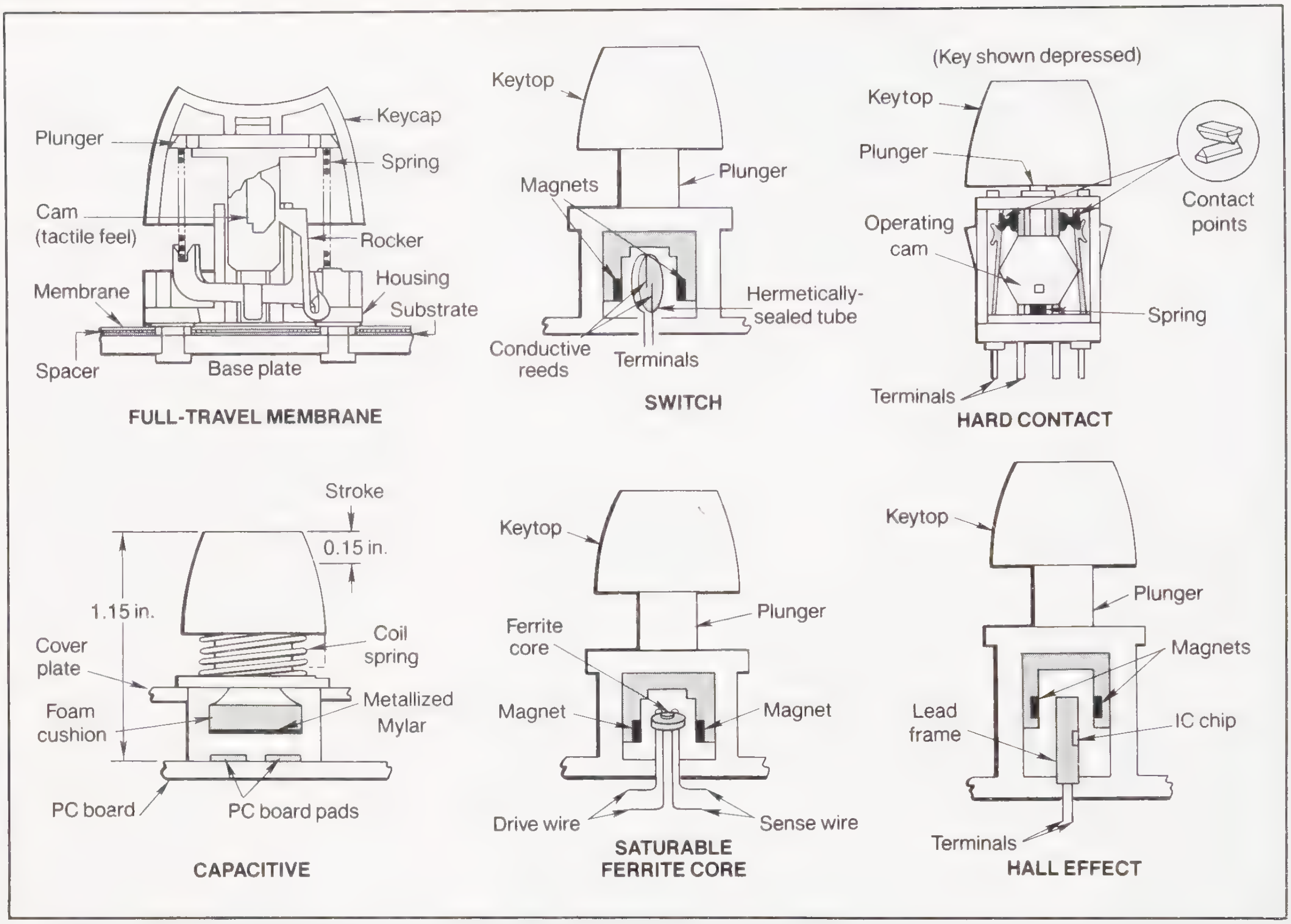
Surface film: Contact area is affected by other factors. For example, all metal surfaces have some kind of surface film. Contaminants such as sulfides condense on metal surfaces and cause chemical reactions. Film thickness depends on the properties of the metal. If the film is softer than the contact material, contact pressure squeezes the film aside at the asperities for metal-to-metal contact. Films harder than the contact material reduce contact area and increase resistance. When contacts with brittle films close, the films are fractured away to expose clean metal.

Oxide film: Contact materials including silver, platinum, palladium, tungsten, molybdenum, and nickel react with oxygen to form tough and resistive surface films. Oxide-forming contacts need relatively large contact forces to fracture these films. Gold-plated contacts, however, are oxide-free and are recommended for high-reliability applications.

Foreign particles: Soft particles may be flattened upon contact closure to allow increased metallic contact. Hard particles may be fractured and swept away by switching action. At the same time, hard particles can cause surface abrasion and wear. And if the particulate matter absorbs moisture, the contacts may corrode or develop local galvanic action.

Since the contact interface acts as a resistor, the heat produced by the closed contacts is proportional to the voltage across them and the current through them. Temperature rise of clean contacts is negligible, but when the contacts start to separate, the number of contacting asperities decreases. As the last contacting asperity decreases its contact area, contact resistance increases until contact voltage reaches melting potential (about 0.5 V for most metals). Molten metal bridges the separating surfaces and finally breaks. During this process some material may transfer between contacts, especially if direct current is interrupted.

Rupture of the molten bridge opens the circuit at low voltage. When source voltage exceeds 14 V, an arc may form as the molten bridge ruptures, delaying circuit opening and pitting the switch contacts. In addition to shortening



continued from page 540

The two layers are normally separated by a thin insulating layer.

Because so many variations of membrane switch systems are possible, few off-the-shelf products are available. Custom switch systems must be specified. Starting costs include NRE and tool-up costs. Price per switch system is reduced by quantity.

In capacitive keyboards, two pads on the circuit board under each keyswitch serve as capacitor plates connected to the drive and sense circuits. A key actuator increases series capacitance, coupling the two elements and creating an analog signal in the sense circuit.

Keyswitch designs in hard-contact keyboards vary widely among manufacturers, but many designs use gold-plated bars to make contact against one another at right angles. The knife-edge contact area is kept small (typically 0.000009 in.^{2}) resulting in high contact pressure (about 5,000 psi).

In saturable-ferrite core keyswitches, magnets straddling a ferrite core saturate the core in the off position. Core saturation inhibits a drive signal from being detected by a sense wire through transformer action. Actuating the key removes the magnetic field and allows the core to act as a transformer, coupling the signal to the sense wire and producing a signal.

Solid-state, Hall-effect keyswitches may have the longest lifetime of all the switch technologies. Switch lifetimes in excess of 2 billion actuations have been reported. Of course, switch lifetime will be limited by some other mechanism. Hall-effect keyswitches incorporate an integrated circuit containing a Hall generator, trigger circuit, and amplifier. Actuating the key moves magnets across the chip, thereby increasing the magnetic flux through the chip. This causes the analog voltage generated by the Hall element to switch the trigger circuit to an “on” state.

A reed switch is a mechanical hard-contact switch. Two conductive reeds are pulled together by a magnetic ring. Because the switches are normally hermetically sealed, switch lifetimes may be as high as 50 billion actuations.

switch life, contact arcing radiates electromagnetic noise.

The higher the switched current, the hotter the arc and the greater the erosion. Contact erosion also increases with longer arc duration because of high switched voltages. Also, contacts that switch inductive currents erode quicker than those with resistive loads. Accelerated erosion is caused by contact arcing that results when the deenergized inductor returns its stored energy to the circuit.

As switch contacts separate, the arc extinguishes when the voltage passes through zero. Therefore, up to a point, the higher the frequency the quicker the arc is likely to extinguish. At 400 Hz, however, arc interruption may be as difficult as with dc loads. High-speed contact separation also decreases arc duration, unless ionized air is present.

The dielectric strength of air decreases as barometric pressure decreases. Therefore, at high altitudes contact arcing occurs at lower voltages and lasts longer. As a result, high-altitude applications require switches with derated load and life specifications.

Mechanical switches

Mechanical switches can be divided into two basic types. The first, commercial and appliance switches, are used in fairly clean environments such as offices or homes. They are not sealed and are generally used for light, low-current applications.

The second type, industrial switches, actuate magnetic contactors or other remote-operated controllers which handle power circuits. These switches must be ruggedly constructed to withstand abuse. They are frequently exposed to oil, solvents, chemicals, and dust. And relatively heavy electrical loads must be switched by the contacts due to high inrush current drawn by the ac electromagnets of the controllers.

TOUCH SWITCHES

A capacitive touch switch consists of two conductive layers on opposite sides of an insulating material such as glass or a printed-circuit board. The conductive layers create a capacitance that decreases when a layer is touched. Interface circuitry converts the capacitance change into a usable switching action to drive logic system or to switch analog signals. There are several types of touch-switch interface circuits available.

Touch-switch control has been combined with control functions on some ICs. One device, for example, varies the duty cycle of a triac that is in series with a light or motor. Touching the sensor briefly causes the state of the triac to simply reverse. Longer activation signals cause the triac duty cycle to slowly change. The change continues as long as the sensor is activated. The direction of change reverses when the triac reaches full on or off.

The switches are available in five basic types: standard duty, heavy duty, heavy-duty oiltight, miniature oiltight, and multilight-control oiltight. The terms *standard duty and heavy duty* are derived from the Standards for Industrial Control Equipment of Underwriters' Laboratories Inc. for normal current and inrush current.

Switching techniques: Manual switches can have one or a combination of switching actions.

In momentary-action switches, the operator pushes (pushbutton or toggle) or twists (rotary) the actuating device and contacts move to transfer the circuits to the second set of contacts. When the actuating force is removed, the actuating device and the contacts return to the original position.

When a maintained-action switch is actuated, the contacts move to transfer the circuits to the second set of contacts. No change takes place until the operator actuates the switch a second time. Then the circuit moves to another set of contacts or returns to the original position.

Mechanical-bail switches have separate switching assemblies, which are interlocked so that actuation of one switch deactivates the previously actuated switch.

A capacitive touch switch consists of two conductive layers on opposite sides of an insulating material such as glass or a printed-circuit board. The conductive layers create a capacitance that decreases when a layer is touched. Interface circuitry converts the capacitance change into a usable switching action to drive logic systems or to switch analog signals. There are several types of touch-switch interface circuits available.

Membrane switches are simple devices in which conductive leads on the underside of a flexible membrane are, at a keystroke, pushed through a hole in a spacer to make contact with conductive leads on a base. Most membrane switches handle loads up to about 1.5 VA at 5 to 15 V.

Circuit breakers

Circuit breakers are manual switches that open themselves under overload conditions. Circuit breakers discussed here are general-purpose types that meet the minimum Underwriters' Laboratories Inc. (UL) standards. Heavy-duty types used in power distribution systems such as oil-filled types, are not included.

Thermal, compensated-thermal, and thermal-magnetic breakers depend upon heat for tripping. Therefore, their characteristics differ only slightly when used on ac or dc.

Operating qualities of hydraulic-magnetic breakers vary because of the magnetic pulses on ac, as compared to the constant pull of dc. On ac, the impedance changes as an iron core moves into the coil. Hydraulic-magnetic breakers have a different ampere-turn ratio for ac than for dc; thus, they should be used on their respective types of current. This is also true of 400 and 60-Hz breakers.

An instantaneous circuit breaker responds to a predetermined value of overload without any purposely delayed action. Any small surge or inrush of current causes the instantaneous breaker to trip and open the circuit. The tripping range is usually 101 to 120% of their current rating.

Most circuit breakers have an inverse time-delay characteristic. With an inverse time delay, there is a point where overload is great enough to operate the breaker instantaneously. In a hydraulic-magnetic breaker, this point can be varied.

In trip-free breakers, the contact arm is independent of the operating handle or mechanism, making it impossible to manually hold the contacts closed during an overcurrent or short-circuit fault.

There are two primary ways of controlling contact arcing. One is by bending the arc so that damage occurs on special surfaces and not on the contact faces. The other is by breaking up the arc into smaller, harmless arcs. Arc protection is mandatory where the circuit breaker is also used as an on-off switch.

Remote tripping can be accomplished by using a two-pole rather than a single-pole breaker. The second tripping element is connected to a remote switch to trip both poles when the switch is closed. Some breakers employ two tripping elements in a single pole. Most remote tripping elements are voltage or low-current sensing elements.

In breakers with an undervoltage release option, the trip circuit is a normally closed circuit. When the voltage in the supply line drops to a predetermined level, the circuit opens and trips the circuit breaker, protecting the equipment from heavy current overload because of a low-voltage condition. The normal range for undervoltage operation is at 30 to 60% of line voltage.

Generally, the voltage must be at least 80% before the circuit breaker can be reset. Most units are instantaneous trip types, but some undervoltage units have a time delay to prevent momentary low voltages from causing circuit-breaker nuisance tripping.

Breakers containing auxiliary contacts usually have a snap-action switch attached to the circuit breaker so that some portion of the breaker mechanism actuates the switch. The switch is usually single-pole, double-throw, and is electrically isolated from the circuit breaker. Some breakers are available with internal auxiliary contacts, but these breakers are hardly ever used.

Overvoltage and overcurrent protectors are available that combine a high-speed voltage-sensing element with a current-sensing circuit-breaker mechanism. If the voltage-sensing element detects the presence of a dangerous transient or overvoltage, it fires and causes the protector to open the line. A third lead for reference must be provided. Installation and reset techniques are otherwise the same as ordinary circuit breakers.

Two-pole breakers are generally used where service requirements are beyond the capability of single-pole units. Circuit breakers with ratings up to 2,500 A and voltages up to 600 Vac or 250 Vdc are generally available. The ac types are normally for single-phase operation.

Three-pole breakers are generally used for multiphase operation. Most two and three-pole breakers are the common-trip type to prevent single phasing of equipment if an overload occurs in only one pole. Generally, a three-pole breaker has a 240-V minimum rating. Circuit breakers can have ratings up to 2,500 A and 600 Vac. Some manufacturers also make three-pole breakers for 250 Vdc applications. Four, five, and six-pole circuit breakers for special applications are also available.

Single-pole types are generally available in current ratings up to 100 A at up to 227 Vac (60 Hz) and up to 250 Vdc.

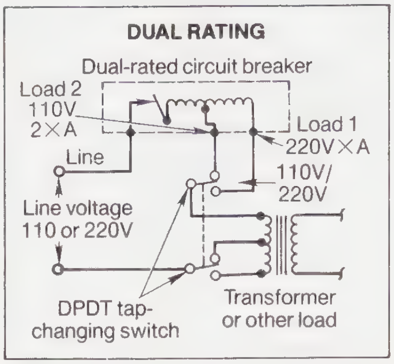
Sizes: Alphabetical frame sizes have been resolved into ampere-designated frame sizes with their respective interrupting capacities. These are listed in NEMA Standard AB 1-1069. Smaller sizes are also available for lower-capacity circuits with voltages of 120 and 120/240 Vac.

All circuit breakers are UL rated at 5,000-A interrupting capacity when the voltage is 250 V or less, or the current is 100 A or less. Circuit breakers rated over these values have an interrupting capacity of 10,000 A. Dc interrupting ratings are available from circuit-breaker suppliers. Higher interrupting ratings are listed in UL Standard 489.

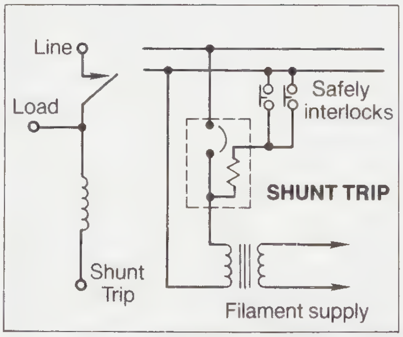
Circuit breakers can have built-in current-limiting fuses in each pole linked mechanically to the circuit-breaker common trip mechanism. The fuses are normally rated higher than the circuit-breaker poles.

Ground-fault interrupters: A ground-fault interrupter (GFI) removes power when it senses a current

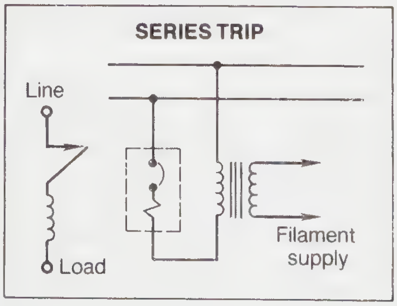
SINGLE-POLE CIRCUIT BREAKERS



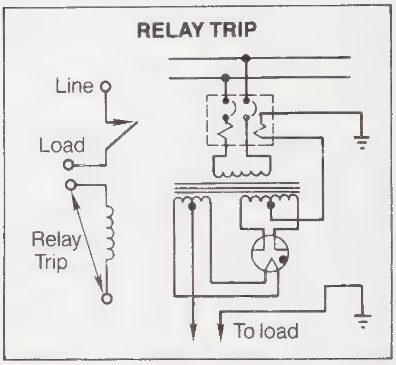
The dual-rated breaker has two current-sensing elements or a tapped sensing element. This circuit permits the breaker to be used on equipment designed for two voltages. The equipment may operate at 20 A at 100 Vac and 10 A at 200 Vac, but the one breaker can be used for protecting the equipment against overload or short circuit at either voltage.



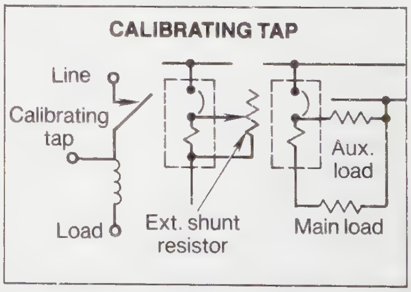
The shunt-trip breaker is like a series-trip circuit with a third terminal added. Shunt-trip breakers are used to remotely trip the load. The remote-trip contacts may be pushbutton or safety devices which respond to temperature, pressure or air flow. Most shunt-trip breakers employ low-current or voltage-trip elements, rather than heavier current elements.



Relay-trip switching contacts are electrically isolated from the tripping element, thus, the breaker has four terminals. This permits using the breaker in two different circuits at different voltages. This design provides a manual reset relay. With relay trip, it is preferable to interlock the circuit so that opening of the circuit breaker contacts deenergizes the coil.



The calibrating-tap circuit is similar to the shunt-trip circuit, but the tripping element is usually a high-current or overload type. The third terminal is connected between the tripping element and the switching contacts. This construction permits bypassing a portion of the current around the tripping element, usually through a suitable fixed or variable resistor. Thus, the trip point can be calibrated by the external resistor. This construction makes it possible to have the breaker control two loads from the same power source.



The most common circuit breaker is the series trip, where the tripping element and circuit-breaker contacts are connected in series between the line and load terminals. Since the contacts and tripping elements are protected in the circuit, they sense the overload or short circuit and open the circuit.

imbalance between the hot and neutral conductors supplying operating power. A ground fault results when a current-carrying part of a circuit accidentally contacts any grounded conducting material. The resistance of the path to ground may be high or low, depending on the nature of the contact.

Low-resistance faults draw heavy current which can trip circuit breakers and open fuses, thereby preventing equipment damage and fire. But when the ground fault has relatively high resistance, such as that of the human body, fault current is not large enough to open circuit breakers and fuses. This same current, however, is sufficient to kill. Furthermore, if the unintentional contact from a live wire to a high-resistance ground is intermittent (such as through vibration) the resultant sparking could trigger a fire — still without opening overcurrent protectors.

Another protection circuit, immersion detection circuit interrupters (IDCI), are smaller and less costly than GFCIs. IDCIs can be built into the power cords of appliances. If the appliance falls into water the IDCI instantly interrupts power. IDCI circuits are less sophisticated than GFCI circuits making them more compact and less expensive.

Electromechanical relays and contactors

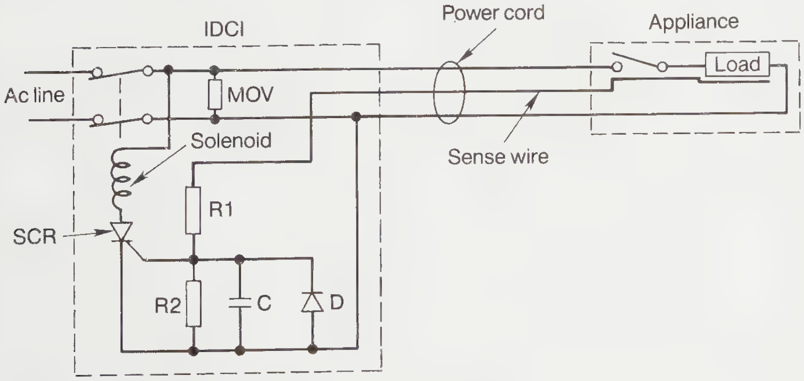
This chapter covers representative general-purpose relays used in the control circuits of most industrial, commercial, and consumer products. Relay names and terminology are in accordance with preferred usage as practiced by the National Association of Relay Manufacturers (NARM).

Relays open and close electrical contacts to operate other devices. They are often used because they cost less than corresponding electronic switches. But some relay qualities are superior to solid-state devices. For example, input and output circuits in relays are electrically isolated unlike those of most solid-state devices. And relays can have numerous contacts electrically isolated one from another. In addition, electromechanical relays are becoming smaller, now available in PCB-mount and surface-mount packages that are suitable for automated soldering.

A CIRCUIT FOR IMMERSION DETECTION

IDCI circuit resides in a wall plug or an ac power cable. A sense wire extends to the appliance. It runs close to all parts that could become electrically hot if the device is immersed. Sense wire positioning is such that water reaches the sense wire before touching an electrically hot part.

When the appliance is immersed in water, current flows in the sense wire on the first positive half cycle of the ac waveform. Current flowing through resistors R_1 and R_2 produces a voltage that is applied to the gate of the SCR. The SCR fires, energizing the solenoid. The solenoid trips a latch, permitting the spring-loaded switch contacts to open and cut power to the appliance.



The switches generally are manually resettable. The reset mechanism is trip free, however. The switch cannot be reset with the appliance immersed — that is, as long as closed contacts produce current in the sense circuit. Nonresettable or one-shot IDCIs are recommended when a single immersion renders appliances unsafe or unreliable.

Capacitor C prevents spurious operation from voltage transients on the line. The MOV protects the SCR from the transients. Resistor R_1 limits maximum gate current. Resistor R_2 prevents turn on from excessive anode leakage current. The diode prevents excessive gate voltage during each negative half cycle of the power line. Typical components are 2N5064 for the SCR, 1N4004 for D, 0.1 μF for C, 2,000 Ω for R_1, and 1,000 Ω for R_2.

One of the advantages of electromechanical relays over solid-state switches is that relays have much lower contact resistance. Contact capacitance is also less, which may benefit high-frequency circuits. Relays are less likely to be turned on by transients than solid-state switches. And relays are less easily damaged by brief shorts or overloads.

Electromechanical relays differ in three important ways from solid-state switches. First, relay coils are highly inductive, and the inductance value is not constant. Inductance is low immediately after energization and increases as current approaches a steady-state level and as the relay armature closes. In contrast, solid-state switches have mainly resistive inputs and a constant input current.

Second, relays have a much longer switching time than solid-state switches. Coil inductance is the primary cause of long switching time, but the mass of armature and contact structures are also factors.

Third, relay coil inductance can produce unacceptably high-voltage transients when the device is deenergized. Protective circuits can reduce the transients to an acceptable level, but they delay relay drop out as well.

Also, relays can be a source of EMI. Arcs at the contacts, for example, are produced when a contact bounces on energization and when contacts open on deenergization. Transients produced by deenergizing the coil are another source. EMI can be severe when switching inductive loads at high current and voltage levels.

Reed relays: A reed relay consists of reed switches within an operating coil. The reeds can be any type of configuration, but the quantity is limited by the coil size. Most manufacturers limit coil size to handle 12 standard switches maximum. To obtain additional contacts, relay coils are connected in parallel. Reed relays are available with contact forms from 1A to 12A, 1B to 8B, 1C to 4C, and combinations of these up to the maximum coil size. Coils may be wound with each magnet-wire size to create a large selection of operating parameters.

Reed-relay contacts typically produce 1 to 3 Vpp at 20 to 30 kHz. The voltage, which is produced by magnetostriction, generally decays about 3 ms after contact closure. Miniature reed relays in 6-lead DIP and surface-mount packages are used for PC-board applications or wherever space is a constraint. Sensitive relays with coil pickup as low as 1.6 Vdc at 40 mW are available.

Mercury-wetted contact relays: Basically, a mercury-wetted contact relay consists of one or more glass switch capsules surrounded by a coil. These relays maintain their original resistance to within 1 mΩ throughout their life.

When two contacts wetted with mercury are joined, the area of contact between the surfaces is somewhat large because a fillet of mercury surrounds the mated surfaces. When the two surfaces are separated, the mercury stretches into a thin filament and then breaks at two points that isolate a thin rod of mercury in the middle. The thin rod then snaps into a ball and drops to the bottom of the switch.

Mercury loss from the contacts disturbs the equilibrium of the capillary system, and more mercury is fed up the armature from the pool. Thus, in effect, the mercury-wetted contact relay provides a new contact surface for each closure.

Armature relays: "Armature relays" refers to relays with pivoted armatures that carry or actuate electrical contacts in response to small control signals.

Ac relays: Alternating current is widely available but is the least flexible power source for relay operations. However, most ac relays designed for 120-Vac line operation tolerate line fluctuations from 102 to 132 Vac.

Most ac applications are for 60-Hz current. Telephone relays operate on 20-Hz current and have construction similar to 60-Hz relays. For 400-Hz current, as found in aircraft, a radical departure from the 60-Hz relay construction is necessary. Reliable performance is attained by rectifying the 400-Hz ac to dc and using a dc relay motor. Packaged relays containing rectifiers are available.

Dc relays: Relays operated on direct current have inherently greater mechanical life expectancy than ac relays. The most frequent source of dc is rectified ac. Often ac ripple influences relay operation. Some dc relays can tolerate ripple, others need filtering.

When the power source is a rechargeable battery, voltage variations of 25% are possible. Relays are usually designed to operate at 75% of nominal voltage. Coils are designed not to overheat at 125% of pickup voltage.

PCB-mounted relays are generally armature devices. Typical devices are either spdt or dpdt and contain contacts rated at 0.5 A to 2 A. Typical operating voltages are 5 to 24 Vdc and 120 Vac. Power dissipation is in the range of 75 mW to 400 mW. These units are often available in sealed versions that can be immersion-cleaned during assembly.

Relay standards: NEMA Class A and B relays are specified in the publication, *Industrial Control,* ICS-1970. These relays control and interlock starters, contactors, and other devices. Relay contacts are also used to open and close circuits to other relays and pilot devices. Relays do not control power-consuming devices, except motors and solenoids drawing under 2 A.

Many manufacturers use MIL-R-5757 as a standard and as a guide for producing Government-acceptable relays. This specification covers relays with contacts capable of switching loads up to 10 A. In general, MIL-R-6106 covers and exceeds the requirements of MIL-R-5757. It also covers relays capable of switching currents in excess of 10 A.

Contacts: Common contact materials are fine silver, coin silver, silver cadmium oxide, and the noble metals. In addition to these materials, special contact finishes may be required for certain applications. For example, if a relay is to be used in a mildly corrosive atmosphere, contacts should have a chromate-conversion coating.

Contactors: Contactors are devices for repeatedly establishing and interrupting electric power circuits. Two types of contactors are defined by NEMA — electronic and magnetic. Electromagnetic contactors are actuated by electromechanical means. They make and break power circuits to such loads as electric furnaces, lights, transformers, capacitors, heaters, and — when overload relays or inherent protectors are used — motors.

The magnet design of an ac contactor consists of a stationary core and a movable armature as in NEMA A and B control relays. Some contactors are of the horizontal design; others have a hinged or pivoted clapper magnet. Coils are available in voltages up to 600 V, commonly in 110, 220, 240, 380, 440, 480, and 500 V for 25, 50, and 60 Hz.

A dc contactor operates like an ac contactor. However, while an ac magnet is laminated steel, a dc magnet is made of solid steel.

Because copper contacts are used on some contactors, the current rating for each size is an 8-hr open rating — the contactor must be operated at least once every 8 hr to prevent copper oxide from forming on the tips and causing excessive contact heating. For contactors with silver to silver-alloy contacts, the 8-hr rating is equivalent to a continuous rating. This rating also applies to contactors mounted in the open without an enclosure. Contactors installed in an enclosure have a rating equal to 90% of the open rating because of reduced contactor cooling.

Stepping switches: Stepping switches connect one or more input circuits to an output circuit chosen from a sizable group of such circuits. The switch responds to current pulses supplied by an external source, or operates by interruption of its circuits through interrupter springs on the switch.

Stepping switches count, sequence, program, select, and control and are often applied in machine-tool controls, conveyor systems, test equipment, and communication switching. Rotary stepping switches are available in many sizes and shapes, primarily dependent on the number of contact points in the bank assembly.

Meter relays: Meter relays provide an analog or digital panel indication of a measured variable together with a switching function when that variable reaches a predetermined value. There are four types of analog meter relays: magnetic contact, locking coil, optical, and solid state. These meters can be used with the user's control circuitry, with a control module option, or with control circuitry contained in the meter (meter-relay controllers).

Switching sensors

Some types of sensors actuate an integral switch in response to a stimulus of some kind. Typical inputs include temperature, centrifugal force, or a simple spring.

Snap-acting switches: Snap-acting switches consist of closely spaced switches that are snapped together or apart by a spring mechanism.

For thermostatic controls, a low operating force and short movement differential permit a temperature-sensitive element to act directly on the operating button of the switch. Thus, heater and motor loads can be controlled without relays. For timing controls, the ability of the switch to operate within close limits of repeatability ensures accuracy of controlled time intervals. In household appliances, the switch can operate directly in fractional-horsepower motor circuits. In machine-tool service, the switch is widely used as a limit switch.

Switches controlling motors, relays, and solenoids must handle inrush currents which may be ten times the steady-state value. And since a lamp filament has low cold resistance in comparison to its hot resistance, inrush current can be twelve times the steady-state current. To switch these loads, the spring mechanism must have enough stored energy to ensure breaking the welds produced by inrush currents. Thus, the switch must have higher operating force and longer movement differential than a switch used for resistive loads.

Contact welding (on make) and arcing (on break) are more severe on direct than on alternating current. Switch failure caused by mechanical interlocking of contacts may result from contact material transferred during making and breaking.

The following guidelines may be applied in low-power circuits:

- For voltages above 6 V and loads over 3 VA minimum, snap-acting switches with silver contacts are adequate.
- When voltage is 6 V or more and the load is between 1 and 3 VA, standard snap-acting switches with silver contacts are relatively safe, provided special nonoutgassing case materials are used.
- When voltage is less than 6 V and the load is less than 1 VA, silver contacts are not satisfactory unless plated with gold or more noble metals; for maximum reliability, solid gold or more noble metals or alloys should be used.

Specifications: ***Movement differential:*** For basic and plunger-actuated switches, this is stated as a range. The low limit indicates the smallest differential obtainable. For switches with leaf or lever actuators, the movement differential is generally the maximum movement of the actuating device that ensures operation of the switch in both directions of actuator travel. Movement differential should be specified as a maximum value instead of range.

Overtravel: This is the distance the actuator moves after snap-over without causing damage. Minimum overtravel that occurs after snap-over is normally not specified. But good practice is to provide for a minimum of 0.002 to 0.003 in. overtravel of the basic switch to ensure adequate contact pressures and some mechanical stability.

Operating force: For most applications it is sufficient to ensure that the actuator force exceeds the upper limit of the operating force range of the switch.

Total overtravel force: This is the force necessary to reach the operating limit position of the switch actuator. For most snap-action mechanisms, overtravel force generally exceeds operating force by two times. This value is usually not specified by manufacturers. If actuator force is limited, the switch might not be driven far enough into overtravel for reliable operation. On the other hand, overtravel force in excess of three times the operating force may overstress the spring mechanism, resulting in decreased mechanical life.

Releasing force: This is the applied force at which switch contacts snap back from operating to normal position. The spring mechanism of the switch should never be used to restore an external actuating device to its normal rest position. If more restoring energy is needed, add auxiliary springs.

Contact force: This is the amount of force holding movable and stationary contacts together. It ranges from 5 gm in the coin switch to more than 150 gm in heavy-duty motor-load switches.

Repeatability: This typically is expressed in terms of operating position, movement differential, and operating force. Maximum repeatability is obtained when the switch is not required to make or break an electrical load. Here, the operating position of a general-purpose switch is repeated within 0.0005 in. for thousands of operations. High-sensitivity snap-acting switches are capable of repeating the operating position within 0.0001 in., and the movement differential within 0.0003 in., even after five million operations.

Limit switches: A mechanical limit switch interlocks a mechanical motion or position with an electrical circuit. A good starting point for limit-switch selection is contact arrangement. The most common limit switch is the single-pole contact block with one NO and one NC set of contacts; however, switches are available with up to four poles.

Limit switches also are available with time-delayed contact transfer. This type is useful in detecting jams that cause the switch to remain actuated beyond a predetermined time interval.

Other contact arrangements include neutral-position and two-step. The neutral-position or center-off type transfers one set of contacts with movement of the lever in one direction. Lever movement in the opposite direction transfers the other set of contacts. With the two-step arrangement, a small movement of the lever transfers one set of contacts, and further lever movement in the same direction transfers the other set of contacts.

Maintained-contact switches require a second definite reset motion. They are used primarily with reciprocating actuators, or where position memory or manual reset is required. Spring-return types automatically reset when actuating force is removed.

Centrifugal switches: A centrifugal switch is actuated by speed only. Simple types consist of speed-sensing units that mount directly on a rotating shaft and a stationary-contact switch assembly. The basic control element is a conical-spring steel disc that has centrifugal weights fastened to the outer edge of its circular base. Fingers on the spring are attached to an insulating spool that rides free of the shaft and actuates the movable switch contact. As the rotating sensing unit reaches switching speed, the centrifugal force of the calibrated weights overcomes spring force, resulting in an instantaneous axial displacement of the spring and the contact-actuating spool.

The contacts switch at one speed as speed increases from zero to operating speed, and at a lower speed as rotation slows from operating speed toward zero. The spring decreasingly opposes centrifugal force as rotational speed increases from standstill until the snap-over point is reached. Then, spring force adds to centrifugal force to axially snap the spool and actuate the contacts. As rotational speed decreases from operating speed, spring force overcomes the centrifugal force of the weights at a lower speed where snap-back begins.

Solid-state relays and I/O

Solid-state relays are much smaller than corresponding single-pole relays. They are also faster, dissipate less power, and withstand a larger number of operations. And unlike electromechanical relays, solid-state switches exhibit no bounce on closing.

Solid-state devices are generally preferred where switch life must be independent of the number of switching cycles, where switching times must be less than 2 ms, and for bounce-free or zero-current switching. They are also generally chosen for applications subject to severe shock or vibration.

Solid-state relays (SSRs) control load currents through solid-state switches such as triacs, SCRs, or power transistors. These elements are controlled by input signals coupled to the switched devices through isolation mechanisms such as transformers, reed relays, or optoisolators. Some solid-state relays also incorporate snubber circuits or zero-crossing detectors to reduce spikes and transients generated by interrupting load current. Since the semiconductor switch can dissipate significant amounts of power, solid-state relays must generally be heat sinked to minimize operating temperature.

Applications are where rapid on/off cycling would quickly wear out conventional electromechanical relays. General-purpose SSRs have on/off cycle lifetimes as high as 100,000 actuations. SSRs that can be actuated with conventional CMOS and TTL logic-level voltages are available.

RELAY LOAD

Selection of a relay primarily depends on load characteristics. A relay should be used as close as possible at its rated load to avoid contact deterioration. Contact loads may be classified into four groups.

Dry circuits: Switching contacts are dry if they do not make or break current. The contacts may carry current after they close and before they open. Usually, gold-alloy contacts or gold alloys working against palladium are best for dry circuits.

Low-level switching: These contacts switch currents ranging from microamperes to a few milliamperes. Open-circuit voltages are below the melting point of the contact material. These voltages and currents are below arcing levels. Gold, gold alloy, or gold alloys mating with palladium are used for low-level loads. However, pure gold contacts or contacts with high gold content working against each other may stick or cold-weld.

Intermediate loads: Contacts switching 400 mA at 26 Vdc may arc slightly. This arcing might produce carbonaceous surface deposits that eventually increase contact resistance, especially in hermetically sealed relays. Usually, this contact resistance does not affect circuit function. Nevertheless, arcing should not be combined with low-energy loads on the same contact. When switching current exceeds 500 mA, gold and gold-alloy contacts are no longer suitable.

Heavy loads: These energy levels cause arcing when switched. The currents and voltages are high enough to break down the resistance of any carbonaceous deposits on the contact surfaces. Relays for heavy loads have contacts made of silver, silver-cadmium oxide, and palladium.

SSR failure modes are primarily determined by the triac or SSR switching characteristics. Most failures take the form of SSR false turn on with no turn-on signal. For example, turn on may occur if operating temperatures exceed the thyristor rating. Also, transients from the switched load or from an ac line can momentarily exceed the thyristor breakover voltage, or steeply rising load voltages can couple into the thyristor input through stray capacitances in the thyristor and cause turn on. This latter effect, called dv/dt turn on, occurs in highly inductive circuits immediately after the circuit attempts to turn off. To combat dv/dt turn on, some SSRs use back-to-back SSRs with reverse bias in place of triacs.

The chief failure mechanism of an SSR is mechanical fatigue in the power semiconductor structure, caused by thermal cycling. However, thermal-cycling effects can be controlled by matching the required load-cycling qualities to relay characteristics. Proper heat sinks for most conditions are available or are an integral part of the SSR.

SSRs generate heat because of the voltage drop present in all semiconductor devices. A 40-A relay, for example, typically drops 1.2 V during conduction and, thus, dissipates 50 W of heat. However, SSR heat generation generally does not require special system design. These devices usually mount on circuit boards or control panels containing other semiconductor devices. Cooling and heat-sinking methods used for these devices are likely to be adequate for the SSR.

Some SSRs designed for controlling ac loads incorporate a zero-voltage turn-on circuit that switches the load on or off only when the power-line sine wave passes through zero. Highly capacitive loads such as lamps and heaters which produce high inrush currents at turn on generate little electromagnetic interference if actuated when line voltage is zero. However, inductive loads such as motors and transformers can saturate during the first half cycle after turn on and produce maximum interference when switched on as line voltage passes through zero. Zero-voltage switches should not be used.

Many SSRs have built-in transient suppressors conducted in parallel with the semiconductor switch output. Common suppressors include RC networks (sometimes called snubbers), Zener or clipper diodes, varistors (voltage-dependent resistors), and RC/diode dump circuits.

I/O modules: Input/output (I/O) plastic encapsulated modules are designed to allow microprocessors or hard-wired logic circuits to control or sense industrial loads.

Ac output modules allow logic-level voltages to control a switch, usually a triac, that turns ac loads on and off. Many incorporate the same types of transient protection and zero-voltage switching available in conventional solid-state relays.

Dc output modules allow logic-level voltages to control a solid-state switch, usually a power transistor, that turns dc loads on and off. These modules are also similar to dc solid-state relays.

Ac input load-sensing modules generate a logic-level voltage (typically TTL or CMOS) that corresponds to the presence or absence of an ac load voltage. As in output modules, load-sensing modules have transient protection and are generally optoisolated. Dc input load-sensing modules perform a similar function for dc loads.

Transducer-sensing input modules accept low-level signals from a specific transducer type, such as thermocouples or strain gages. The module conditions this signal through operations such as linearization and amplification. The module output can then be sent to an a/d converter for conversion to digital data. Some transducer-sensing modules also provide frequency or current outputs for signal conditioning. ■

Power supplies

Electronic equipment requiring dc power must adjust the ac input to a usable level with transformers or switching transistors and use a rectifier stage to convert the ac to dc. Primary (nonrechargeable) or secondary (rechargeable) batteries generally power portable equipment and use a wide variety of chemistries.

Modern power supplies typically use solid-state rectifiers for converting ac line voltage to some desired value of dc. The dc output voltage may be unregulated or regulated to any degree of precision and stability. Power supplies have different filter arrangements for eliminating undesirable ac ripple components from the dc output. They also vary in size, weight, efficiency, voltage range, and many other important characteristics.

Power-supply fundamentals

Four forms of power supplies are widely used today: unregulated, ferroresonant, series-regulated, and switching-regulator types. Differences include maintaining constant voltage output, cost, efficiency, size, weight, and amount of ripple.

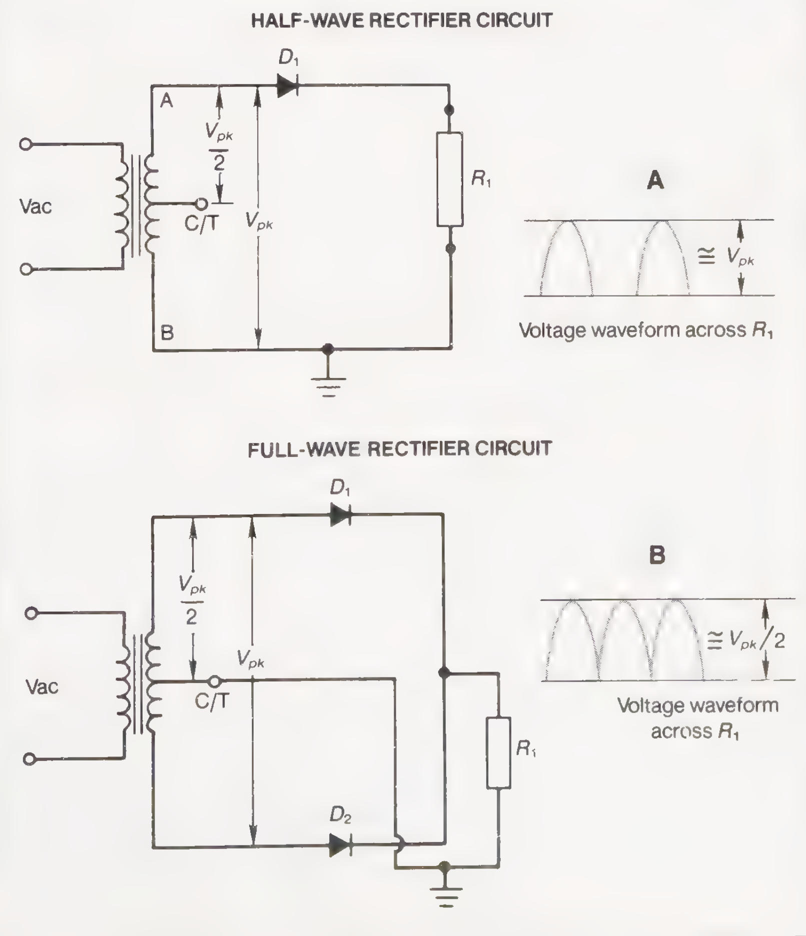
Unregulated power supplies find very limited use today, since the output dc voltage is proportional to the input ac voltage. Output voltage fluctuates in step with input variations as well as changes in load impedance. Also, ripple voltage can run as high as 10% of the output dc voltage. Even with filter networks on the output, the remaining ripple and load regulation may be insufficient for most modern electronic circuits. But some components — relays, solenoids, and indicating lamps, for example — do not usually require a precision and filtered voltage. Thus, an unregulated power supply may be desirable for these circuits because unregulated supplies are simple, reliable, and inexpensive. Additionally, unregulated power supplies are typically more efficient and dissipate less heat than regulated power supplies with the same output voltage and current.

Regulated power supplies are the type most widely used. Two fundamental designs are the linear series-regulated and the switching power supply. Although switching power supplies are considered by many to be the new wave of technology, they have been around for many years. But, because of recent improvements in semiconductor components, capacitors, and transformers, they can be made more reliable, simpler, and less costly than just a few years ago. They are well suited for applications requiring small size, high efficiency, and moderately good regulation. On the down side, however, switching power supplies generate voltage spikes and noise in their outputs and can radiate EMI/RFI because of switching transients. These unwanted signals can seriously interfere with le-

POWER SUPPLY RECTIFIER CIRCUITS

Circuits A and B show classic rectifier configurations. The peak voltage across the load resistor, R_1, in the half-wave rectifier circuit is equal to a half-cycle of peak voltage at the transformer secondary, Vpk (minus the rectifier voltage drop of about 0.7 V). Circuit B uses the transformer center tap and both halves of the cycle to lower the ac ripple content — hence, the full-wave rectifier. Note the output voltage of the full-wave rectifier circuit is 50% of the half-wave rectifier for the same secondary voltage, Vpk. The output ripple voltage from both power

continued on page 550

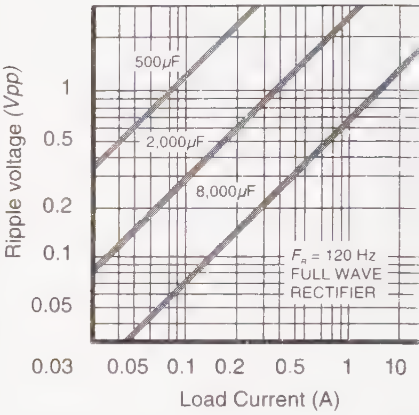

HALF-WAVE RECTIFIER CIRCUIT
D_1
A
$V_{pk}/2$
Vac
C/T
V_{pk}
R_1
B
A
$\cong V_{pk}$
Voltage waveform across R_1
FULL-WAVE RECTIFIER CIRCUIT
D_1
$V_{pk}/2$
V_{pk}
Vac
C/T
R_1
D_2
B
$\cong V_{pk}/2$
Voltage waveform across R_1

gitimate signals and completely mask others. Thus, carefully designed power supplies should include effective shielding, bypassing, and filtering to prevent propagating noise into sensitive circuits.

Linear-regulated power supplies are typically larger and less efficient than switching power supplies, but cost less and are more precisely regulated. The linear power supply is used by engineers needing high gain, wide dynamic range, low noise, and fast response for laboratory and systems power requirements.

High gain brings better regulation of load and source effects and results in higher precision and more accurate voltage settings. Wide dynamic range makes it possible to control or program the power supply over a wide voltage

RIPPLE VOLTAGE VS. FILTER CAPACITOR VALUE (FULL-WAVE RECTIFIER)



continued from page 549

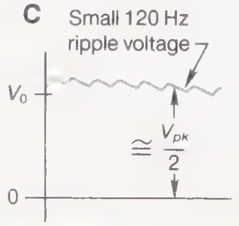
supplies are too high for most electronic circuits, but some applications — driving small motors and indicating lamps are not adversely affected.

The figure shows the average dc output, Vdc, and ripple, V_r (peak-to-peak), for a full-wave power supply with a small load. As the load demands more current, the stored charge in the filter capacitor (section a-b) will deplete more deeply between pulses, and cause a higher ripple.

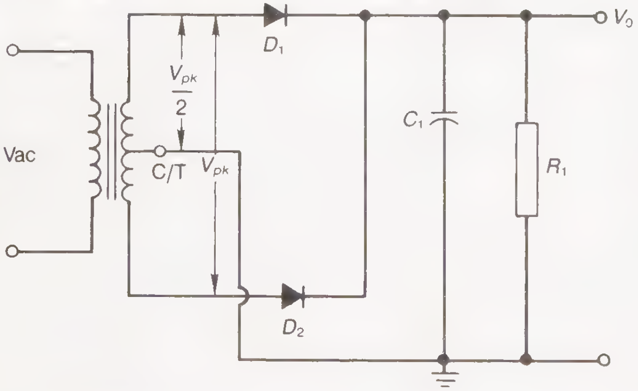
Chart shows the effect of the filter capacitor size (μF) on the output ripple (Vpp) vs. load current (A). As the capacitor increases in size for any value of load current, the ripple content drops.

When the output ripple voltage needs to be lower than obtainable with a single-filter capacitor as shown, *LC* (inductor-capacitor) filter networks may be added to the output, or active voltage (or current) regulators may be required. (See *Types of Power Supplies*).

A filter capacitor of sufficient size added to the output as shown in Circuit C will store charge and supply current to the load between peaks of rectified ac voltage. This smooths the output to provide dc with less ripple content.

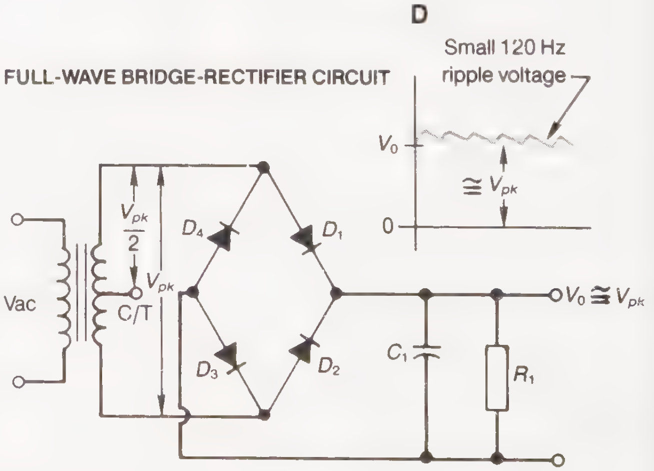


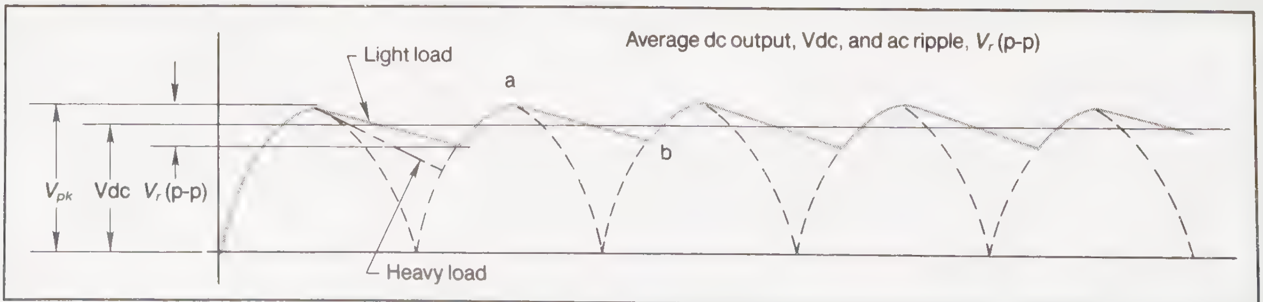
FULL-WAVE RECTIFIED OUTPUT IS FILTERED BY C_1



The bridge-rectifier configuration shown in Circuit D is a full-wave power supply with the same characteristics as Circuit C, but the entire transformer secondary winding may be used to obtain twice the output voltage.

FULL-WAVE BRIDGE-RECTIFIER CIRCUIT

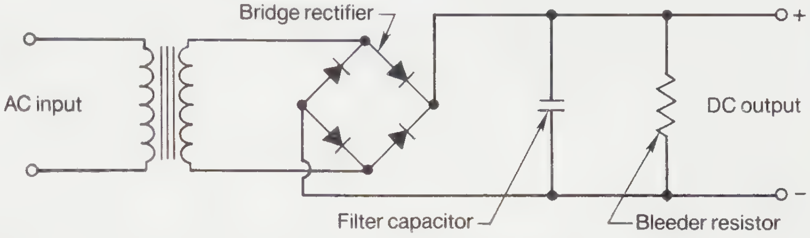



Average dc output, Vdc, and ac ripple, V_r (p-p)

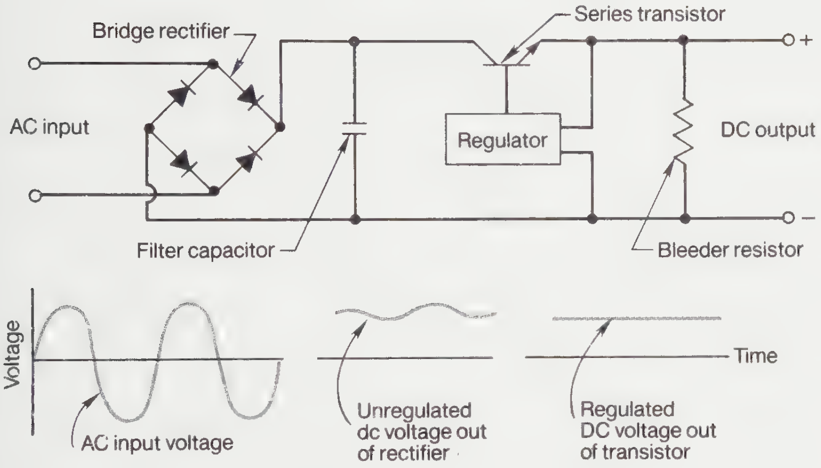
TYPES OF POWER SUPPLIES

Unregulated power supplies contain a power transformer, rectifier, filter capacitor, and bleeder resistor. As a result of this simplicity, they are more reliable, efficient, and less costly than the others. However, output voltage varies in direct proportion to input voltage changes, and output voltage also is a function of load. In addition, the output voltage contains appreciable ripple. Thus, unregulated power supplies are used for applications that do not require precise voltage control. When necessary, output ripple is reduced by providing external-filter capacitance and *LC* networks. The input can be fed from an adjustable autotransformer if manual voltage control is needed. Unregulated supplies are typically used for powering relays, solenoids, indicating lights, and similar loads.

Unregulated



Series-Regulated

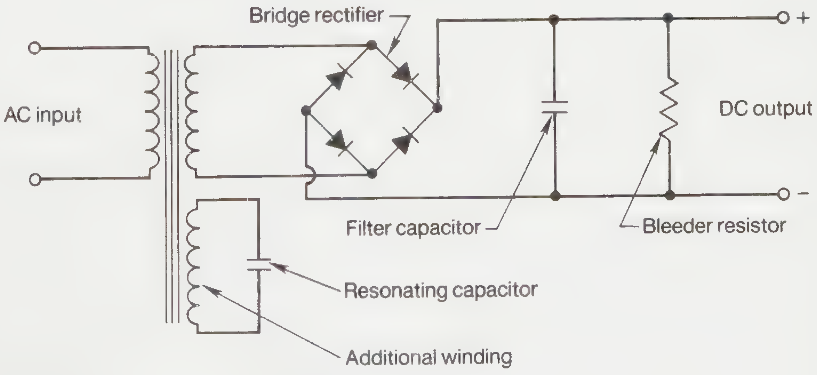


Series-regulated power supplies have rectifiers and filters similar to those on unregulated supplies but have a power transistor in series with the output. A sensing circuit monitors output voltage, adjusting voltage drop across the transistor to hold output voltage at a preset level. Efficiency of series-regulated power supplies is lower than that of other power supplies as a result of power dissipated in the series transistor. And output power per unit volume is also lower. But series-regulated power supplies have excellent line and load regulation, a low temperature coefficient, and very little ripple. Series-regulated power supplies are highly reliable, and are used in instruments, computers, controllers, and other applications.

Ferroresonant power supplies also contain a power transformer, bridge rectifier, filter capacitor, and bleeder resistor. But the transformer has an additional winding which is connected to a capacitor. This inductive-capacitance circuit resonates at line frequency, saturating the transformer core for a portion of each input power cycle. As a result, output-voltage levels vary, and load regulation is somewhat better than an unregulated supply. Filter capacitors are also more effective than other power supplies because the output voltage from a ferroresonant-type transformer has a clipped waveform.

Costs are significantly less than that for other regulated supplies. Efficiency and reliability are second to those of unregulated supplies. However, ferroresonant power supplies are heavier than other types. And because ferroresonant supplies are tuned, they can be used only at rated input power frequency. Different transformers must be used for frequency variations as small as 60 to 50 Hz because a 1% line-frequency variation will change output voltage by about 1¼%. Thus, ferroresonant power supplies are generally used where moderately good voltage regulation is required but where input frequency is constant. Tape-motor drives and electrolytic processes represent ferroresonant applications.

Ferroresonant



Power supply specifications

		OUTPUT VOLTAGE							
		Regulation							
Type	Input	Line	Load	Ripple	Adjustment	Efficiency	Overvoltage protection	Overcurrent protection	Remote sensing
		(%)	(%)			(%)			
Unregulated	0-132 V* 47-440 Hz	*	10	5 to 10%	Transformer taps or autotransformer	80 to 95	Not req'd	Fuse	No
Ferroresonant	117v ± 15% 57 to 63 Hz	1	3 to 10	0.5 to 5%	Transformer taps	70 to 85	Not req'd	Self-limited	No
Switching-regulated	105 to 125 V 47 to 440 Hz	0.05 to 0.5	0.05 to 0.50	5 to 20 Vrms 20 to 150 Vpp	Continuous through output voltage range	65 to 85	Yes	Yes	Yes
Series-regulated	105 to 125 V 47 to 440 Hz	0.005 to 0.1	0.005 to 0.1	0.25 to 5 Vrms 1 to 15 Vpp	Continuous through output-voltage range	30 to 50	Yes	Yes	Yes

*Output voltage is proportional to input voltage.

range, either by internal or external command signals. Low noise or ripple produces better resolution of control. Response speed indicates how rapidly the power supply can respond to a control input or to a load disturbance to take action. There is a large and growing number of uses that demand "smart" linear power supplies. Such supplies usually connect to controllers (often via the IEEE-488 bus) to integrate, sum, step, range, and otherwise interact with the command loop of modern automatic test equipment (ATE) systems.

Ferroresonant power supplies: Another power supply that should be considered is known as a ferroresonant type. Regulation takes place within the step-up or step-down transformer by core saturation means. This type costs less than series-regulated and switching power supplies. Ferroresonant power supplies are not as precisely regulated as the other two, but produce sufficiently precise voltages for many applications.

Specifications

Input ratings: Typical power-supply modules are designed and rated to operate with their inputs connected to lines delivering 105 to 125 Vac. Most 115-Vac power systems maintain line voltage within that range. However, line voltage for heavily loaded systems can drop below 105 V, and line voltage for lightly loaded systems or for systems close to utility substations may rise appreciably above 125 V. When connected to a low-voltage line, a regulated power supply may not produce rated dc output voltage. And power supplies tend to overheat when subjected to high line voltage. Since power system loading and, thus, line voltage varies widely during operation, line voltage for a proposed power-supply application should be checked. If low or high voltage is expected, that fact should be included in specifications for a power supply.

Standard power-supply modules rated for 210 to 250-Vac input are also available. These are suitable for application on most U.S. standard 230-Vac systems. However, 210 to 250-V rated power supplies may not be suitable for European power systems. Those systems are typically rated 220 V, and the resulting 10-V margin for low voltage is not sufficient for most 220-V systems. Thus, if a power supply is applied to a power system rated 220 V, the power supply should be designed specifically for that voltage.

Several power supplies are designed and rated for operation on 50 Hz (a power frequency used in Europe and other parts of the world) and on 400 Hz (a power frequency used on aircraft and other vehicles) as well as on 60 Hz. However, when power supplies are used on those other frequencies, output current must often be derated and fuse sizes changed from those standard for 60-Hz operation. Thus, power-supply specifications should be checked if 50 or 400-Hz operation is contemplated.

Output ratings: Ratings for power-supply output voltages are nominal or approximate values, and voltage output may be adjustable. But the precise output voltage at any moment during operation depends on many factors. For an unregulated supply, output voltage varies in direct proportion to input voltage and is further modified by load changes. For regulated power supplies, output voltage more precisely matches the rated value but does vary slightly with changes in line voltages and load current. Furthermore, output voltage is influenced by power-supply temperature coefficient and stability. Instantaneous output voltage is affected by the ripple present.

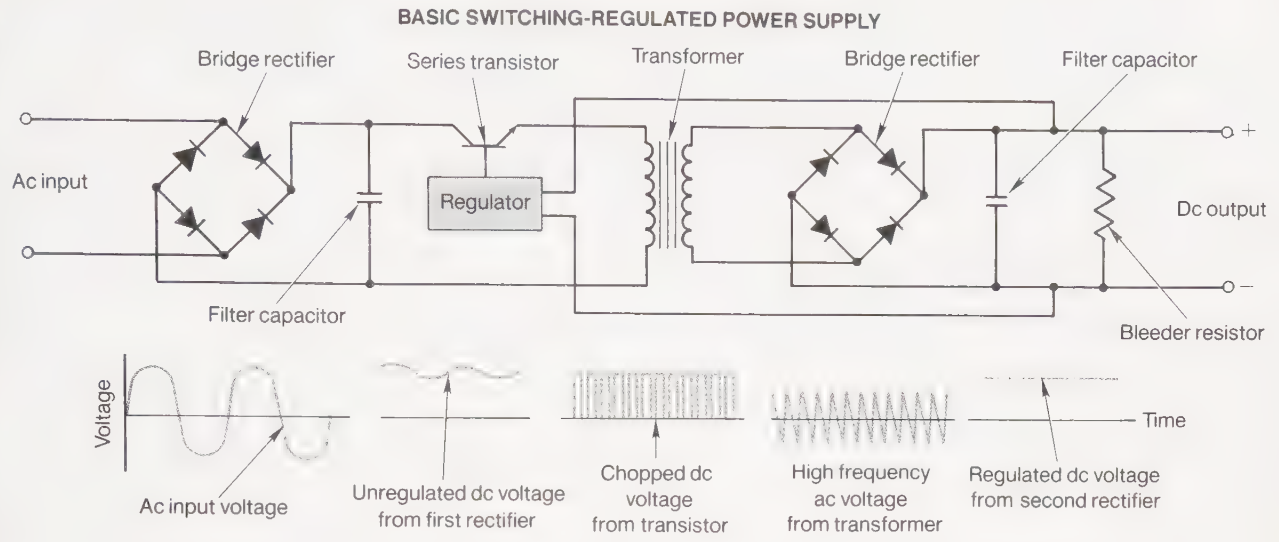
If a power supply with adjustable output voltage is required, the minimum adjustment acceptable should be chosen. Power supplies with narrow adjustment ranges generate less heat and are less costly than those having wide-range adjustments. Power supplies having a narrow adjustment range cannot be grossly misadjusted, a common cause of equipment failures, especially during initial start-up.

Power-supply output-voltage circuits frequently are electrically isolated or "float" with respect to the power-supply chassis. Thus, low-voltage supplies can be connected in series to obtain higher voltages. However, power-supply components and insulation are often rated for 200 V maximum. Thus, power supplies should not be connected in series if the resulting output would exceed 200 V unless the power-supply maker approves that application.

Regulating line and load: Line and load-regulation ratings relate to voltage regulation. Line regulation is the maximum steady-state amount that output voltage changes as a result of a specified change in input line voltage. Line regulation is typically expressed as the percent change of output voltage caused by a 10% change of input voltage. Line regulation runs from 0.005% for the best series-regulated supplies to about 1% for ferroresonant supplies.

Load regulation is the maximum steady-state amount that output voltage changes as a result of a specified change in load. Load regulation typically is expressed as the percent change of output voltage caused by increasing load from half load to full load. Load regulation runs from 0.005% for the best series-regulated supplies to 10% for unregulated supplies.

Regulating circuitry normally controls voltage at power-supply output


BASIC SWITCHING-REGULATED POWER SUPPLY
Bridge rectifier
Series transistor
Transformer
Bridge rectifier
Filter capacitor
Ac input
Regulator
+
Dc output
−
Filter capacitor
Bleeder resistor
Voltage
Time
Ac input voltage
Unregulated dc voltage from first rectifier
Chopped dc voltage from transistor
High frequency ac voltage from transformer
Regulated dc voltage from second rectifier

The series transistor in the switching power supply turns on and off at a high rate of speed. Little power dissipates in the transistor during the transition between saturation and cutoff. Therefore, efficiency is higher than the dc-series type, but noise is higher and regulation lower.

terminals, and is satisfactory if the load is near the power supply. But current in wires connecting a power supply to a load produces some finite voltage drop which may not be tolerable. However, remote sensing is available for most power supplies which regulates voltage at the load.

A regulated power supply can fail in a mode that results in excessively high output voltage. An overvoltage protection circuit, a crowbar, is available as an option for most power supplies. This protection should be obtained if load failure due to power-supply overvoltage would be unacceptable.

Ripple and noise: Ripple identifies undesired ac components in the dc output voltage, and includes the portions of the ac input voltage waveform that remains after filtering. It also includes electrical noise developed within a power supply. Ripple is generally stated in mVrms or in mVpp for series-regulated and switching-type power supplies. But ripple is given in percent of nominal-rated dc voltage for ferroresonant and unregulated supplies. Ripple in the output of series-regulated supplies is typically 0.25 to 5 mVrms and 1 to 15 mVpp. Switching supply ripple runs from 5 to 20 mVrms and 20 to 150 mVpp. Ripple for ferroresonant supplies typically is 0.5 to 5% and that for unregulated supplies is 5 to 10%.

Most power-supply applications require dc voltage containing very low ripple. For applications providing power for high-gain or low-power-level amplifiers, for example, power supplies should be chosen on the basis of an mVpp specification rather than an mVrms specification.

Two characteristics that affect output voltage, but are important only in critical applications, are temperature coefficient and stability. Temperature coefficient is the percent change of output voltage as a result of a 1°C change in ambient temperature.

Power-supply stability is the percent change of output voltage as a function of time. A stability figure is often stated for warm-up, based on a short time period, typically 20 min, as well as for long term, typically a 24-h period.

Current ratings: All power-supply modules have current ratings that are based on some specific ambient temperature range. These current ratings should never be exceeded. However, most manufacturers include a safety margin in their current ratings and overspecification with respect to current rating would be wasteful.

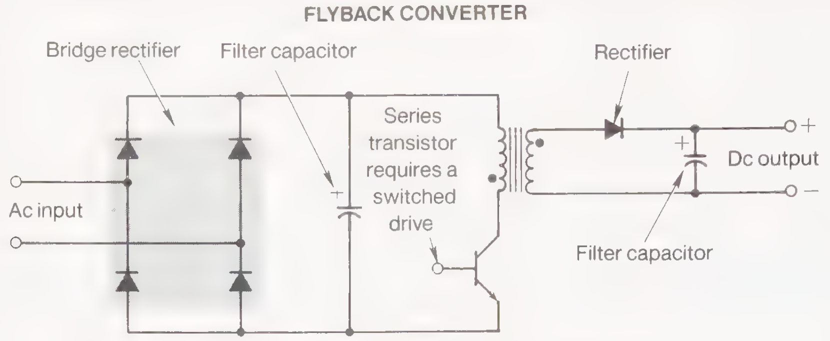
Power supplies are generally rated for either 0 to 55°C or −20 to 71°C ranges. But current ratings for most power supplies are based on a 55°C maximum ambient. Current ratings for higher temperatures are derated from those for 55°C. A power supply should not be operated in an ambient temperature exceeding its maximum rating unless it is approved by the manufacturer. For higher ambients, a manufacturer generally indicates a reduced maximum current rating.

The ambient temperature for a power supply is the temperature of the air immediately surrounding the power supply when it is operating with its associated equipment. That temperature generally is appreciably higher than the free-air temperature of the room in which the equipment is operating. A power supply is typically the hottest item in an electronic system, and its enclosure is often used as a heat sink to dissipate this heat. Thus, adequate air circulation must be provided to prevent ambient temperatures from exceeding ratings.

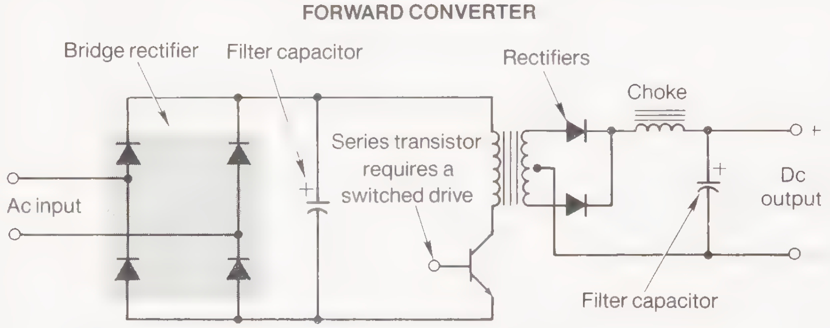
Fuses provide overcurrent protection for unregulated power supplies. In some cases, they are furnished as power-supply components. Fuses are sometimes used with regulated-type power supplies, but in such cases, they only provide backup protection. Primary overcurrent protection for regulated power supplies is provided by a current-limiting feature. This feature limits its current output to a value set at intervals 10 to 50% above rated current. When that point is reached, voltage drops off, preventing further current increase.

Switching-regulated power supplies

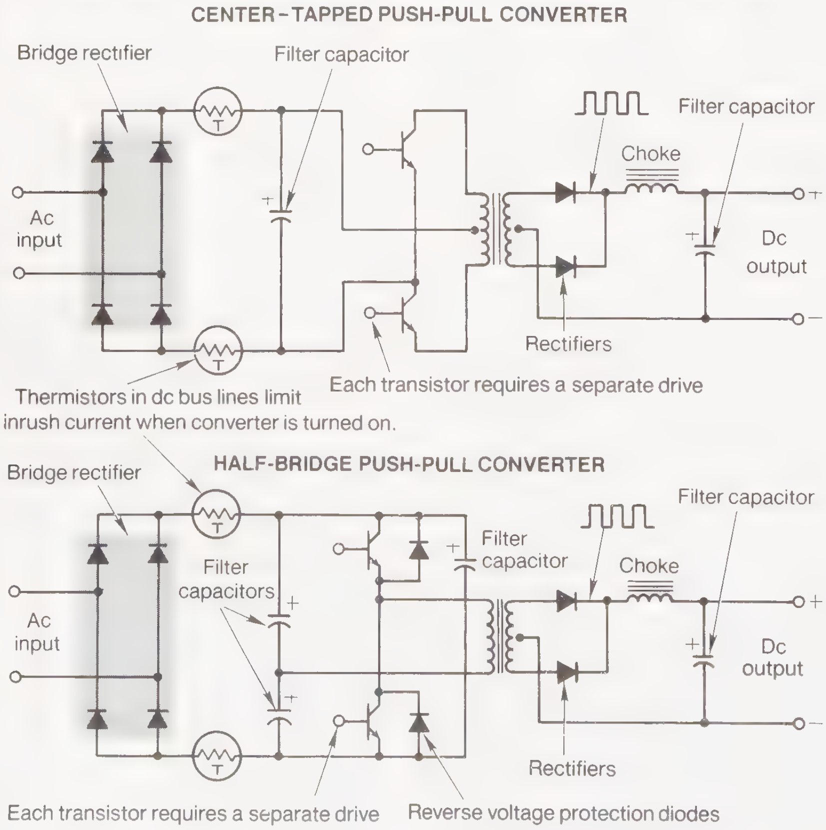
The most common type of power supply today is the switching supply. These units use pulse-width modulation (PWM) to regulate their output.



The flyback converter is the least-expensive supply type by virtue of its low part count. But it is only economical up to about 100 W and has poorer regulation than more complex types.



The forward converter has good load and line regulation and is most cost effective between 80 and 200 W. While it appears to be similar to the flyback, the base-drive switching signal is different.


CENTER-TAPPED PUSH-PULL CONVERTER
Bridge rectifier
Filter capacitor
Filter capacitor
Choke
Ac input
Dc output
+
−
Rectifiers
Each transistor requires a separate drive
Thermistors in dc bus lines limit inrush current when converter is turned on.
T
HALF-BRIDGE PUSH-PULL CONVERTER
Bridge rectifier
Filter capacitor
Filter capacitor
Filter capacitors
Choke
Ac input
Dc output
+
−
Rectifiers
Each transistor requires a separate drive
Reverse voltage protection diodes

The center-tapped and half-bridge converters have the best regulation of the three basic types and are widely used in the 150 to 600-W range.

Supplies today employ several different PWM circuit configurations. In all cases, the PWM logic signal drives the switching power transistor, and the power transistor, in turn, drives the load.

The switching power transistor turns on and off rapidly, producing a chopped dc voltage. The chopped dc voltage is fed to a transformer which converts the pulsating dc to high frequency ac. This ac is then fed to a second bridge rectifier which produces the final dc output. A sensing circuit continuously monitors the output voltage, adjusting the switching duty cycle to maintain a constant voltage output.

Switching power supplies are more efficient than series-regulated ones because little power is dissipated in a switching transistor producing little heat. Switching supplies are physically smaller than series-regulated types because components operating at switching frequency (typically 20 kHz) are much smaller than those used in a nonswitching supply operating at 50 to 60 Hz. These power supplies are well suited where compactness, efficiency, and moderately accurate regulation is required. But switching-type power supplies are electrically and, sometimes audibly, noisy. Thus, they are unsuitable for powering circuits that are sensitive to electrical noise unless those circuits are adequately filtered and shielded. Finally, switching power supplies are generally more costly than other power supplies.

Switching frequencies are continually rising. The advantages of higher frequencies include reduced component size, lower ripple voltage, higher power per unit volume, and quiet operation. While 20 to 30 kHz seems to be the most widely used frequency today, 100 to 500 kHz are also being used. And some PWM-type integrated circuits are capable of handling switching frequencies to 1 MHz and more.

Circuitry that produces the PWM drive signal is now available on numerous standard ICs. These chips sport a variety of features. Many of the features protect the chip and power supply from start-up current surges, overvoltage, and short-circuit faults. Others allow the supply designer to build in more flexibility, as in remote on/off control, remote error sensing, and proportional load-current sharing. Custom ICs and microprocessors are now being built into more complex power supplies, especially those that interface with host computers through standard buses.

Supply makers say that options

quickly become standard features as users demand better products. And as systems become more complex, standard features become basic necessities. Overvoltage protection, adjustable voltage, and active soft-start are among the most common capabilities found on today's power supplies which were once options. Additional options that are candidates for standardization include specialized EMI filters, power fail and power valid indicators, and current balance circuits for proportional load sharing.

Switching is typically implemented in one of three ways. The first is a flyback circuit configuration. It is suitable up to 100 W and is the most economical of the three types because it contains the fewest number of parts. A second is called a forward converter. It is most cost effective between 80 and 200 W. The third is a more complex type that comes either as a center-tapped push-pull circuit or a half-bridge push-pull circuit. These two are widely used in the 150 to 600 W range.

An off-line switcher rectifies the incoming ac main voltage and is considered a dc-to-dc converter. Rectified and filtered 115 Vac produces about 145 Vdc; therefore, some converter designs work from 145 Vdc input as well as 115 Vac. The input rectifiers become steering diodes that allow either input lead to be positive or negative. And off-line models with a 115/230-Vac selectable input handle up to 290-Vdc input.

Switchers that operate directly off the mains require an input current surge-limiting circuit. Since there is no transformer impedance to help limit current charging the filter capacitors, peak currents can be high enough to destroy the rectifiers.

In its basic configuration, the flyback switcher contains one transformer, one pulse-width-modulator circuit, one power transistor, and one output diode. The transformer steps down voltage, provides line isolation, and acts as an inductor. When the power transistor switches on, current in the primary stores energy in the transformer core. The polarity is such that the diodes do not conduct. When the transistor switches off, the voltage polarity reverses and flies back, passing current through the output diode to the output capacitor and load. The amount of energy stored in the core is varied by the on time of the PWM and transistor.

As power increases over 100 W, the flyback transformer size increases rapidly because of increased current requirements. Also, the saw-toothed waveform produced by the flyback circuit needs twice the peak current for a

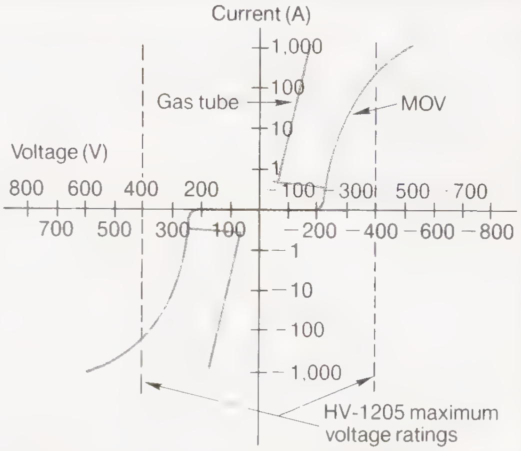
COMPARING SURGE SUPPRESSORS

No matter how rugged solid-state power supplies are, they must be shielded from power-line surges. These transients can be several kilovolts in magnitude at frequencies in the megahertz range. The protection circuit must do two things: reduce incoming voltage swings and absorb excess energy.

An *RC* low-pass filter with a shunt clamping device provides surge protection. It is located between the supply and the line. The low-pass filter removes high-frequency components of the surge, while the clamp diverts low-frequency voltage. Carbon-composition resistors limit input current and dissipate surge energy whenever incoming signals exceed clamp voltage. Resistors also dissipate most high-frequency energy because of the 0.5 μF capacitor presents a low impedance across the IC input.

A metal-oxide varistor (MOV), placed across the input, serves as the clamping device. MOVs are constant-voltage devices that conduct above a certain voltage. For a 120-Vac input, a MOV such as the Harris V130LA20A can be used. It has a high impedance until its terminal voltage exceeds 180 V peak (130 (Vrms). At that point, current begins to flow through the device. Further current increase causes the voltage to rise.

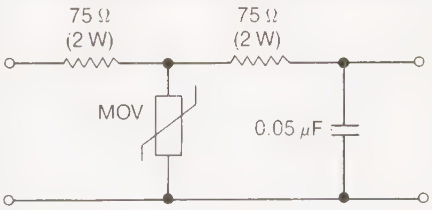
Current-voltage relations for gas tubes and MOVs. At high currents, gas tubes let through less surge voltage than MOVs. But MOVs respond faster and are more widely used for applications of only a few hundred amps.



The first 75-Ω resistor limits current through the MOV to about 75 A for a 6,000-V surge. At 75 A, the MOV clamps to a data-sheet value of ±300 V. This circuit meets the requirements of IEEE Standard 587 Category A and B and ANSI Standard 37.90a.

Another type of surge suppressor that clamps voltage swings is the gas-discharge tube. Together with the MOV, they are the two most widely used suppressors for protecting low-power systems. Gas tubes commonly protect telephone users from lightning strikes. The tube shorts the line while sinking thousands of amps of current. Because of its SCR-like current-voltage relation, it is referred to as a crowbar clamps.

Superior clamping techniques give gas tubes some of the lowest let-through voltages of any available surge suppressor. A long response time of several microseconds, however, limits its ability to respond to high-frequency bursts. MOVs, on the other hand, respond in nanoseconds but are limited to surge currents of a few hundred amps. At up to 6,000 V, both types are equally effective with the HV-1205 because of its ±400-V breakdown capability. Beyond 6,000 V, or when repetitive surges are expected, gas tubes are a better choice.



An input surge-suppression circuit based on a metal-oxide varistor (MOV). Alternatively, a gas-discharge tube could replace the MOV.

given power level compared to a forward converter. Over 100 W, the maximum allowable peak current for the flyback transistor occurs quickly.

A forward converter uses an additional flywheel diode and a filter choke in its output compared to the flyback circuit. Also, the transformer steps the voltage up or down and provides line isolation.

During the switching transistor on-time, current flows through the output inductor to the filter capacitor, so the inductor stores energy. When the transistor turns off, the stored energy continues to flow through the flywheel diode, causing less output ripple voltage than the flyback design. The peak current is only half that of the flyback, but the forward converter has two magnetic components which increase size and cost.

As power demands further increase, push-pull circuits are widely used up to about 600 W. Two versions are available. One is a center-tapped push-pull circuit, and the other is a half bridge. The center-tapped circuit looks like two forward converters with alternate on periods. Both converters share a single output inductor. Depending on the pulse width, the inductor supplies current to the capacitor while both switches are open. Both push-pull circuits produce the lowest ripple voltage of all switchers.

While switch-mode power supplies have many advantages over linear types, they also have several drawbacks. Among them is the production of noise during switching which requires special care in circuit design and printed-circuit-board layout to filter. A well-designed linear power supply has an output noise level of less than 1 mVpp, compared with 10 mV p-p for the same capacity switcher. Both conducted and radiated noise and switching frequency harmonics extend into the radio frequency spectrum. Designers must keep these noise levels within specifications that are set and controlled by regulatory agencies around the world.

Another drawback concerns limited response to dynamic load changes. Unlike linear supplies with very low output impedance, load voltage correction in a switcher takes place only after a full cycle of the oscillator completes. In addition, the control-loop time constant is set to integrate the output voltage change over several cycles to prevent continuous ringing.

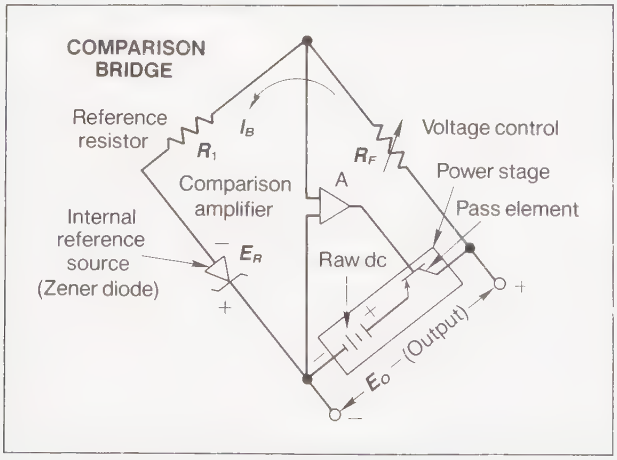
Typically, line and load regulation for linears are about ten times better than switchers for the same voltage and current ratings. But this quality comes at the expense of power dissipation. For example, a 2:1 ratio in efficiency of a switcher over a linear can account for as much as a 6:1 advantage in power dissipation at an 800-W level.

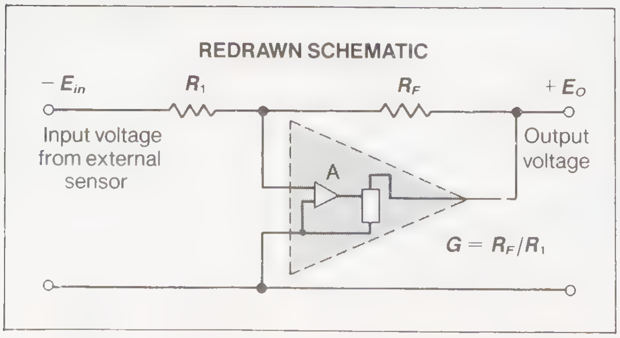
POWER SUPPLY ANATOMY

The heart of an operational supply is a comparison bridge. The bridge compares the supply output voltage E_O to a voltage reference E_R through bridge resistors R_1 and R_F. Assuming large amplifier gain, $E_R/R_1 = E_O/R_F$ or $E_O = E_R(R_F/R_1)$, where E_R is generally a 6.2-V drop across a precision Zener diode. The effect is to amplify the reference voltage to any output level with a gain set by R_F/R_1. Substituting an external source for E_R allows the supply to multiply the external source voltage by the ratio of R_F/R_1.

The bridge current I_B generated by E_R/R_1 flows through R_F to develop control voltage E_F. Bridge nulling action produces a voltage drop across the pass element such that $E_O = I_B R_F$. Generally, the reference resistor R_1 is selected to produce a convenient level of current, such as 1 mA, that generates 1 V of output for every 1,000 Ω of feedback or control resistance. This ratio is often called the programming ratio.

In practice, the operational power supply bridge is often depicted as an operational amplifier with degenerative feedback. Here, the amplification symbol represents both amplifier and power stages. The open-loop gain of such operational supplies can range from 100,000 to 1 million (100 to 120 dB). If used with 40 dB of feedback, operational gain extends from 1,000 to 10,000, but typical gains are 0.1 to 1,000.





Operational power supplies

Power supplies available today offer more than just a source of voltage or current. Devices called operational supplies can serve as sophisticated amplifiers giving a flat response from dc to 20 kHz. They also handle up to 400 W continuously. These attributes give the supplies control characteristics analogous to those of servoamplifiers.

There are differences between operational supplies and servoamplifiers, however. One difference is in power ratings. Servoamplifiers generally are rated on the basis of average power to a load, but operational supplies carrying the same rating actually provide more power because the specification applies to continuous power output.

Bridge circuits

In control applications, operational power supplies are alternatives to other sources, ranging from simple SCR bridges found in electric drills to elaborate servoamps. The benefits of operational power supplies in these situations are high precision and moderate cost.

The easiest way to understand how operational power supplies operate is through a comparison with conventional linear supplies. Linear supplies generally include a reference voltage, a feedback arrangement to monitor output voltage or current, a high-gain amplifier, and a series-pass element that regulates the output. The devices regulate output voltage by comparing it to a fixed reference, then changing the output based on load current.

Operational supplies, on the other hand, can be considered high-gain amplifiers. Each contains a bridge that controls a conventional operational amplifier. The amplifier is driven by a sensor whose voltage output is compared to a reference. The resulting difference unbalances the bridge and sets amplifier output.

The voltage that the sensor generates can be thought of as feedback. Thus, operational supplies use feedback to vary or modulate their voltage output. This property allows the supplies to generate signals approximating those of a servocontroller.

The typical device serving as a reference in these supplies is a Zener diode. The substitution of an external source or other transducer for the internal reference allows the supply to change its output in response to external conditions. These conditions may be a change in speed, temperature, velocity, or other similar physical entities.

Because a sensor provides the feedback that sets the supply output, the sensor voltage may be said to program the device. The programming voltage can be produced in several ways. The simplest method is to put a potentiometer and battery, or other voltage source, across the feedback terminals. Or, a resistor can be placed across the terminals, and a separate source then provides a control current.

In most modern operational supplies, a shunt-regulated Zener diode produces a stable reference voltage across a precision series resistor to produce a 1-mA (1,000 Ω/V) or 10-mA (100 Ω/V) feedback current. The feedback resistor takes the form of a variable control mounted on the supply front panel. This control varies power-supply output voltage.

A remote feedback resistor or transducer can also vary the output. This type of remote control can provide motor-speed regulation. Here, a tachometer or Hall-effect device generates a dc feedback signal proportional to motor speed.

In operation, the tachometer output generally connects in series with an opposing dc supply. The difference between the two sources controls the main power supply driving the motor. A change in motor speed generates a tachometer voltage that makes the supply compensate for the error.

Controlling light

Operational supplies are frequently used to regulate the intensity of heavy-duty light sources such as xenon or arc lamps. The uniform illumination of a monochronometer is a typical objective. Light sensors typically provide the regulating feedback. These sensors include photomultiplier tubes and photovoltaic or photoresistive semiconductors.

Photovoltaic silicon photocells are the most convenient sensors. Their output, however, usually requires some voltage amplification before use as a command signal. A small dc amplifier is generally used to increase the sensor signal level. This amplification also contributes to loop gain and, thus, improves light intensity regulation.

Photoresistive cells can also sense light intensity. Such cells generate a variable terminal resistance as a function of incident illumination. The process is one of resistance-to-voltage translation, for which programmable power supplies are well suited. This translation procedure depends on a constant bridge current producing a linear voltage with changes in sensor resistance.

For example, the power supply is said to be controlled at an Ω/V ratio equal to the reciprocal of the bridge current. At a bridge current of 1 mA, the control ratio is 1,000 Ω/V. Thus, for every 1,000 Ω change in photoresistance, the supply output changes 1 V.

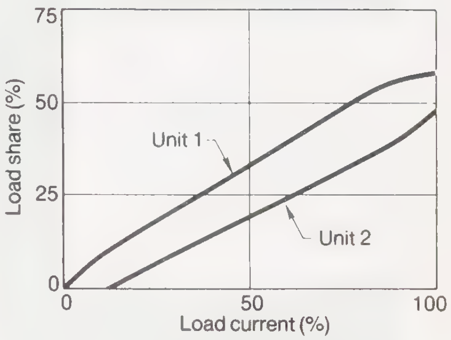
A similar technique provides temperature control. Here, the output of a programmable supply can generate heat directly by powering resistive heaters. Use of temperature-sensing feedback elements, then, produces precise proportional heating.

One or several thermistors form the temperature feedback sensor. These sensors program the output of a small dc supply which, in turn, controls the main operational power source. Feedback voltage to this source would have the sensitivity of the thermistor in Ω/°C divided by the Ω/V ratio of the translating power supply.

Typical temperature controllers handled with operational supplies would be in the 1,000-W category, suf-

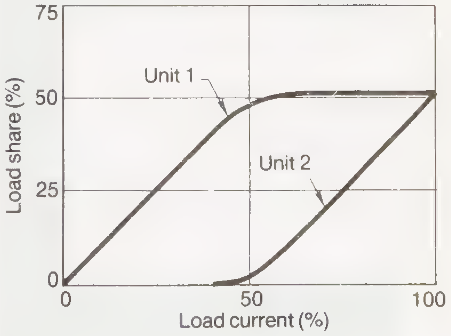
LOAD SHARING OF PARALLELED POWER SUPPLIES

LOCAL SENSE MODE



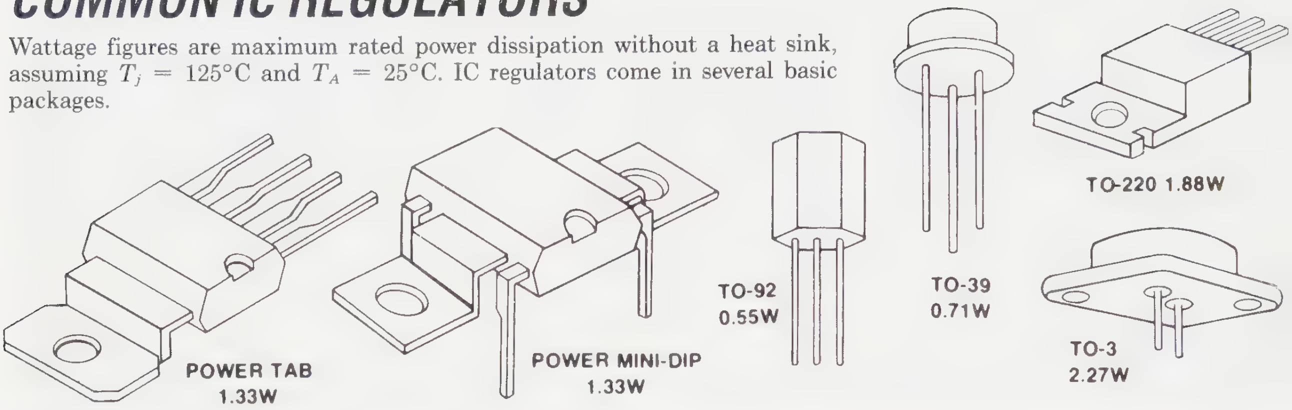
Load current tends to be shared reasonably well when furnished by suitably adjusted power supplies paralleled in local-sense mode. But voltage regulation may be poor. Where the two paralleled power supplies are operated in remote-sense mode, voltage regulation is better. But one unit tends to furnish all current up to its current-limit setting.

REMOTE SENSE MODE



COMMON IC REGULATORS

Wattage figures are maximum rated power dissipation without a heat sink, assuming $T_j = 125°C$ and $T_A = 25°C$. IC regulators come in several basic packages.



ficient to heat a 27-ft^3 temperature chamber. A typical application might use one supply to heat radiators, and two other smaller supplies in opposition to provide a differential programming input.

One of these small supplies monitors temperature from thermistors placed around the temperature chamber. The other small supply provides a reference voltage serving as the adjustable temperature-control command. With a forward gain of between 150 and 200 in the main supply, such an arrangement can control temperature to better than 0.1°C over long periods.

A similar technique often controls electrochemical processes. Many electrolytic processes proceed at rates governed by the voltage appearing at an immersed reference electrode. This voltage level frequently determines which of two electrolytic reactions take place.

Such a process is known as a controlled potential electrolysis. The devices used in the procedure are called potentiostats. An operational supply and simple feedback circuit can comprise a potentiostat. Here, the reference electrode is in the feedback loop, and the supply powers a working electrode. The voltage appearing between the reference and working electrodes is compared to the output of a small command supply. The difference signal then controls the output of the main supply.

Voltage regulators

A critical aspect of power supplies is dc supply-voltage stability. In addition to powering circuits, a precision dc voltage is often used as a reference to which voltage signals are compared for decision making. If reference voltage fluctuates wildly, so does the decision making of the system.

To solve this problem, one large voltage regulator is often located at or near the power source. However, one problem with this approach is the voltage drop along the supply line caused by wire or printed-circuit resistance. The resulting variable voltage throughout the system often degrades regulator performance. Another problem with using a single regulator is the various impedances of the system. Common impedances between terminals provide paths for unwanted coupling. This requires added decoupling and bypass circuitry which, in the long run, can degrade local regulation.

These effects can be reduced or eliminated by using individual regulators at each critical circuit location.

The need for a voltage regulator is determined by the load and voltage supply, rather than supply alone. Selecting the correct regulator requires a thorough knowledge of load requirements. Several questions should be answered:

- What is the maximum range of voltages over which the system must perform?
- How much current does the system require?
- How much ripple voltage can be tolerated?
- How much voltage drift with temperature is acceptable?

IC regulators: A temperature-compensated reference voltage is developed on the IC and compared with the output voltage of an error amplifier in IC regulators. This amplifier has a low-temperature drift to maintain good output-voltage stability with changing temperature. The error amplifier drives an output stage consisting of a Darlington pair. The chips also contain the necessary bias and protection circuits including short-circuit protection, thermal shutdown, and pass transistors.

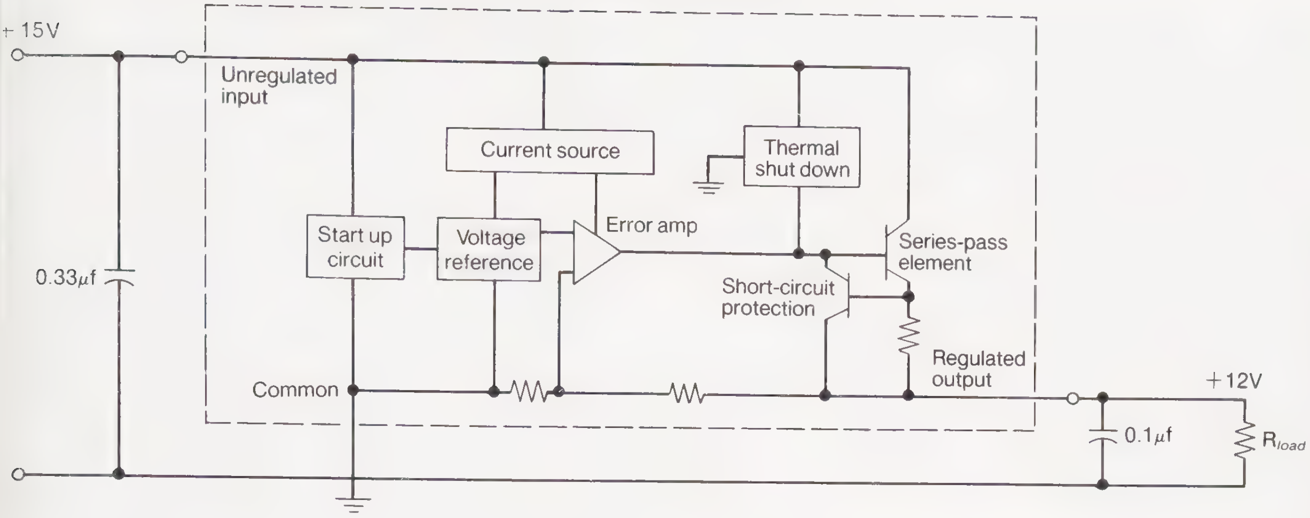
Unlike other ICs which operate at minimum power levels, voltage regulators are generally operated at or near their power limits. For this reason, the maximum power dissipation $P_{D(max)}$ is a crucial parameter. The power dissipated is in the form of heat and is a function of the device package, junction temperature, and ambient temperature. (Junction temperature is the average temperature of the monolithic IC chip located inside the regulator package.) Maximum permissible junction temperature $T_{J(max)}$ is specified in device data sheets.

Other related thermal specifications are thermal resistance from the junction to the case θ_{JC} and to ambient (room air) θ_{JA}, thermal resistance from the case to the heat sink θ_{CS}, and thermal resistance from the heat sink to ambient θ_{SA}.

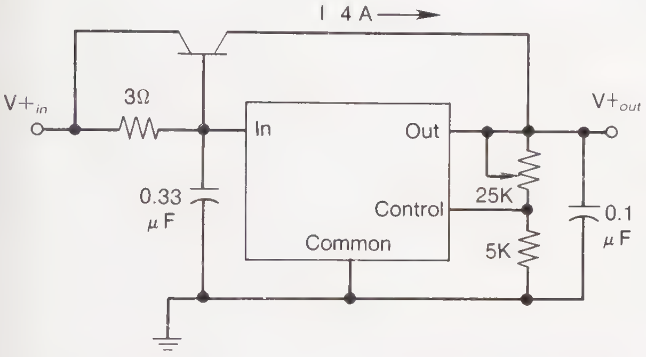
For optimum circuit performance, junction temperature of a semiconductor must be kept at or below its maximum rating. Since reliability of semiconductors improves as the operating junction temperature decreases, heat sinks are often used to help dissipate heat. To determine if a heat sink is necessary, first determine junction temperature of the device from $T_J = T_A + \theta_{JA}P_D$ = junction temperature, °C; T_A = ambient temperature, °C; θ_{JA} = junction-to-ambient thermal resistance; and P_D = power dissipation, W.

Actual power dissipation P_D is obtained from $P_D = I_{OUT}\,(V_{IN} - V_{OUT}) + V_{IN}I_Q$, where V_{IN} = input voltage; V_{OUT} = output voltage; I_{OUT} = output current, A; and I_Q = quiescent current, A (standby current, no load).

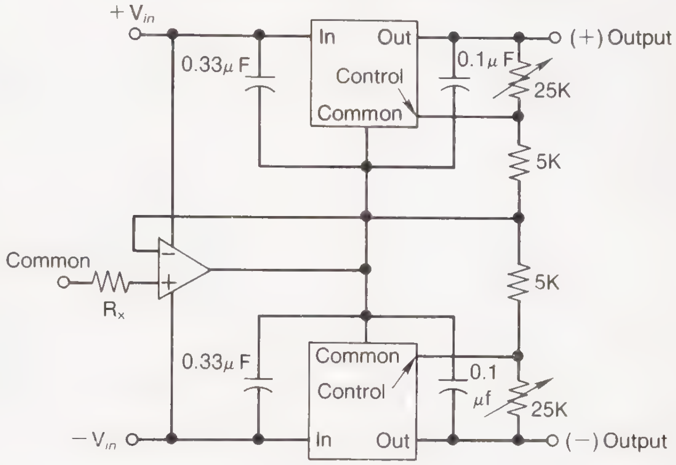
It is good practice to keep T_J about 25°C below the maximum value specified by the manufacturer. Typically, THREE-TERMINAL REGULATOR



FOUR-TERMINAL REGULATOR WITH PASS TRANSISTOR



ADJUSTABLE DUAL TRACKING REGULATION



IC REGULATOR OPERATION

Diagram shows a three-terminal device. Output voltage is compared with a reference voltage by the error amplifier. Any difference between the two voltages causes the error amplifier to increase or decrease current flow through the series-pass transistor to remove the error signal. Thus, the transistor acts like a variable resistor whose value changes inversely with load current to maintain a constant output voltage. To operate properly, IC voltage regulators must be connected to external components. In general, nonprecision regulators require fewer components than precision regulators. About 50 different regulators are available in various IC packages and with various fixed and adjustable-output voltage ratings. Three-terminal regulators require half the external components used with precision regulators. Regulation is not as good, but output current is greater. Greater output current capacity of a four-terminal regulator results from adding a resistor in series with the input and adding an external series-pass transistor. However, the added circuitry also removes regulator short-circuit protection. Adjustable dual-tracking regulation results from combining both positive and negative regulators with op amps. This type regulation is needed for MOS circuits and many op amps and comparators.

these maximums are 150°C, therefore, T_J should be kept at or below 125°C. Maximum recommended power dissipation is determined by $P_D = (T_J - T_A)/\theta_{JA}$. Therefore, external heat sinking is necessary if $I_{OUT}(V_{IN} - V_{OUT}) + V_{IN}I_Q > (T_J - T_A)/\theta_{JA}$.

To determine the amount of heat sinking required, substitute $(\theta_{JC} + \theta_{CS} + \theta_{SA})$ for θ_{JA} and solve for θ_{SA}. Junction-to-case thermal resistance, θ_{JC}, is supplied by the semiconductor manufacturer. Case-to-sink thermal resistance, θ_{CS}, and sink-to-ambient thermal resistance, θ_{SA}, are generally furnished by the heat-sink supplier. This is difficult to determine analytically because it is a function of so many variables, such as contact area, contact pressure, interface materials between the IC and the heat sink, and whether convection or forced-air cooling is used.

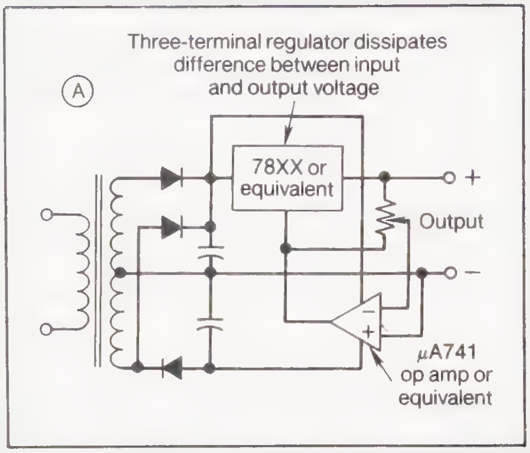
Power supplies should not be connected in parallel to provide higher output current unless allowed by the manufacturer. A few millivolts difference in output voltage of two power supplies connected in parallel can cause an unbalanced condition: the power supply having the higher voltage delivers most or all of the current while the other power supply idles. Moreover, current from the higher-voltage supply may flow into the other supply and damage it.

Power-supply efficiency is the ratio of output to input watts. The differ-

REGULATING VARIABLE-VOLTAGE POWER SUPPLIES

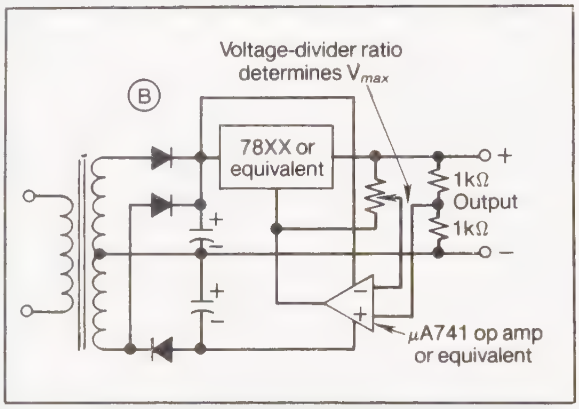
Circuit A provides an output voltage adjustable from 0 V to the nominal output voltage of the three-terminal regulator. The circuit is simple and inexpensive, but output power is limited. Since the unregulated input voltage is fixed and independent of the adjustable output voltage, thermal dissipation of the three-terminal regulator increases as output voltage decreases. Therefore, the maximum possible load current is least at the lowest output voltage, an unwanted feature.

Circuit B is a modification of Circuit A that doubles maximum output voltage. Adjusting the voltage-divider ratio provides any required V_{max} within the constraints of the breakdown characteristics of the regulator and operational amplifier. But, Circuit B has the same load-current restriction as Circuit A.



Three-terminal regulator dissipates difference between input and output voltage

μA741 op amp or equivalent

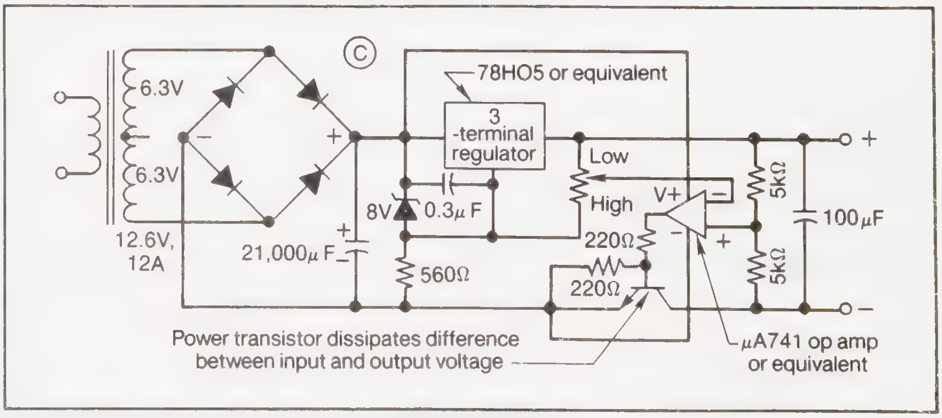


Voltage-divider ratio determines V_{max}

μA741 op amp or equivalent

Circuit C is complex and costly, and overcomes the shortcomings of Circuits A and B. Here, the three-terminal regulator supplies the reference voltage and provides current-limiting and thermal shutdown. The regulator does not dissipate the difference between input and output voltage. Instead, this function is provided by a separate power transistor mounted on an appropriate heat sink. Under normal operating conditions, the Zener diode maintains a constant 3-V drop across the series-pass transistor inside the voltage regulator independent of output voltage. This arrangement not only increases output capability but also improves regulation against line-voltage changes.

For a 0 to 10-V output range, the unregulated input voltage should be 16 V ±10%. At a 1-A output current and a 1-V output voltage, the entire regulator must dissipate up to 17 W, but only 3 W are dissipated in the three-terminal regulator. More than 13 W are dissipated in the power transistor.



78HO5 or equivalent

Power transistor dissipates difference between input and output voltage

μA741 op amp or equivalent

ence between input and output power is dissipated by a power supply as heat. Unregulated, ferroresonant, and switching-regulator power supplies have efficiencies as high as 85%. Series-regulated supplies are considerably less efficient (typically 40%), but offer better regulation and lower ripple than other types.

Forms: There are no standards for constructing power supplies, but common forms are produced by many manufacturers. For example, regulated power supplies in encapsulated packages having solder pins for PCB mountings are widely available. These typically have ratings of 15 W or less. Similar encapsulated units having screw terminals (instead of solder terminals) are also listed by some manufacturers. In addition, power supplies are commonly constructed on printed-circuit cards for mounting, along with other circuit cards, in standard card cages. Printed-circuit-card units are typically rated less than 30 W.

Many power supplies are housed in perforated modular steel or aluminum cases. These typically are shoebox-shaped and have dimensions that vary with power ratings. The case acts as a heat sink. Most of these modular power supplies have screw terminals on one end for I/O connections. Threaded mounting holes are generally provided on bottom, side, and rear, permitting various mounting arrangements.

Many manufacturers make open-frame power supplies with ratings similar to those of enclosed units but having their components mounted exposed on "U" or "L" brackets. These are less costly than enclosed units, partly because enclosure cards are eliminated. Sometimes, these open-type power supplies may be less costly as a result of using lower-cost components. This difference is reflected in reliability. Warranty periods for open-type power supplies usually run from 60 days to 1 year, whereas enclosed unit warranties are generally for 5 years. Many open-type power supplies require relatively more derating for high-temperature ambients than do enclosed power supplies.

Plug-in power supplies are also widely available. These typically have an octal or 11-pin plug similar to that used on plug-in relays. Regulated plug-in units generally are rated up to 60 W, while unregulated plug-in supplies have ratings as high as 140 W.

High-voltage ICs

Several chip makers can now produce integrated circuits that operate directly from ac lines. These ICs are expected to drastically change the makeup of power supplies. For one thing, they may eliminate the need for transformers for some types of supplies. However, it appears that one of the first types to be affected will be low-current versions in nonisolated applications.

A high-voltage IC process is credited for the first major change in low-power supplies in 20 years. Single-chip supplies were, in the past, not feasible because breakdown-voltage barriers prevented conventional ICs from use in off-line applications. Transformers were needed to step the voltage down to a safe level for the electronics.

Conventional linear ICs typically operate over a ±15-V range. Maximum voltage is limited by the concentration of the background dopant in the silicon or the level of electrical isolation between transistors, whichever is most restrictive.

The ICs are fabricated on low-resistivity silicon wafers to reduce power loss and improve device speed. Wafer resistivity is lowered by heavy doping. But *pn* junctions formed in heavily doped material have low breakdown voltages. High-voltage discrete transistors, on the other hand, are made with high-resistivity, lightly doped silicon substrates.

Isolation is usually achieved by surrounding each transistor with a *pn* junction. When the junction is reverse biased, the depletion region blocks leakage current flow into or out of the device. The drawback with junction isolation is that it takes up wafer space and requires activation power.

Breakdown voltage improvements in high-voltage ICs are possible for two reasons. One, the starting substrate material is high-resistivity silicon. Secondly, isolation junctions are replaced by a solid insulator. A dielectric layer of glass a few microns thick isolates each transistor. Dielectric isolation takes up less space and consumes no power.

One of the first applications of the high-voltage IC process is a single-chip power supply called the HV-1205. The 1205 survives inrush currents of up to 1.2 A and is immune to both spikes and severe brownout. Full power is delivered through sags down to 30 Vac. The IC packs into an 8-lead miniDIP the functions of a transformer, rectifier, and a 3-terminal regulator. It hooks directly to any industrial ac line and can

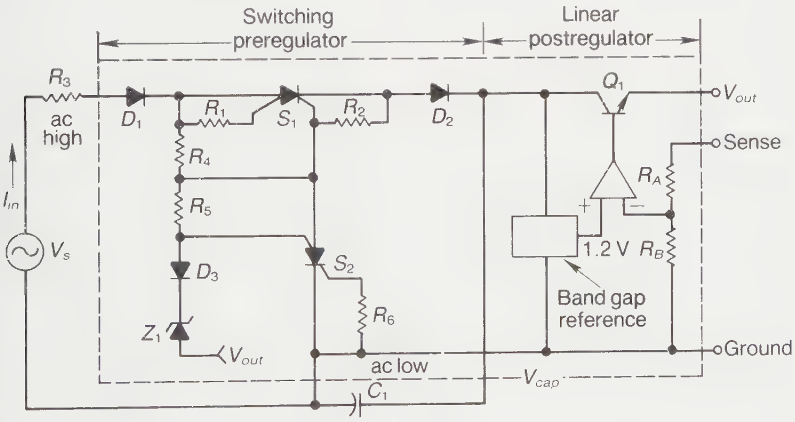
HOW THE HV-1205 WORKS

Conduction of the gate-turnoff SCR, switch S_1, occurs on the front half of the ac cycle when line voltage exceeds the voltage on the storage capacitor C_f. When the capacitor charges to the value of the Zener diode Z_1 plus the output voltage V_{out}, SCR switch S_2 turns on, turning S_1 off. During the remainder of the half cycle, current from R_4 keeps S_2 latched on, holding S_1 off. In the off state, S_1 withstands ±500 V. S_2 unlatches during the negative half cycle.

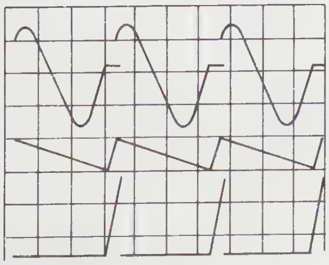
Storage capacitor C_f takes charge from the ac line and supplies it to the load through a band-gap referenced, op amp-like postregulator. Feedback resistors R_A and R_B form a voltage divider that scales the sense voltage to 5 V. When V_o is connected to the sense pin, the feedback loop is closed and V_o is forced to 5 V.

If the loop from V_o to sense is closed through an external voltage divider or Zener diode, V_{out} will go to whatever voltage forces the sense pin to 5 V. Selection of external components allow the chip to deliver fixed 5 V or variable outputs to 25 V. Power dissipation in the chip is held constant by an internal Zener feedback network that holds the preregulator 5 V above the output.

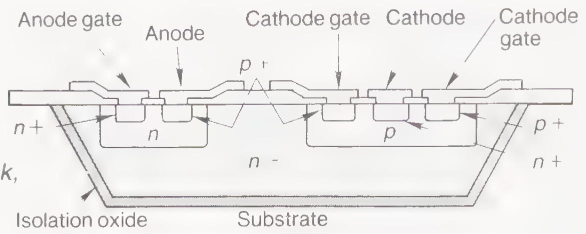
For applications that interface with people or equipment, isolation is usually provided directly at the interface. Self-isolated panels and switches can protect operators, while the equipment interface is isolated by relays, optocouplers, or signal transformers. Embedded controllers can reside within the controlled equipment when isolation is not an issue. Sense-and-display functions need no isolation.



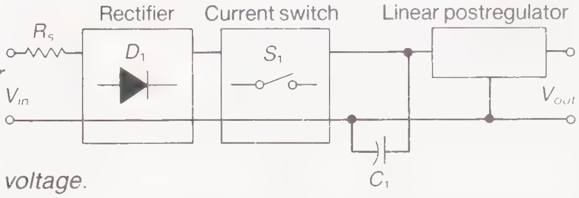
Circuit diagram of power-supply IC. SCR S1 serves as a current switch. And an op amp-like postregulator stage offers users choice of dc output voltage.



Waveforms of the ac input voltage (top) and current (bottom) show that energy transfer takes place at the beginning of each cycle. The storage capacitor voltage (middle) contains ripple from the charge/discharge cycle of the preregulator.



Cross section of high-voltage current switch reveals the insulating oxide that isolates transistors. The dielectric layer, only a few microns thick, replaces conventional junction isolation.



Block diagram of the power-supply IC. A switching preregulator rectifies and reducing incoming line voltage, while the postregulator provides a stable output voltage.

deliver clean low-voltage dc power.

An advanced switching design provides up to three outputs in the range of 5 to 25 Vdc at up to 50 mA. In industrial uses, for instance, the chip can simultaneously power a 24-V relay, provide 10-Vdc sensor excitation, and source a 5-V logic signal. A battery backup configuration allows uninterrupted operation during power loss. The IC automatically charges the battery during normal ac operation.

The 1205 is basically a nonisolated switching power supply that operates at line frequency. A high-efficiency switching preregulator rectifies and reduces the incoming line voltage, while a linear postregulator removes ripple and provides load regulation. Because the chip is functionally simple, it is easy to design into protected power systems.

Batteries

Common dry batteries — the type used in flashlights, toys, and portable instruments — come in three grades. The least expensive are called general purpose. Those labeled heavy duty cost somewhat more, and alkaline batteries cost the most.

Differing prices for the three grades primarily result from battery chemistry. General-purpose and heavy-duty batteries are both thought of as carbon zinc. But carbon-zinc batteries can use two different systems. General-purpose batteries typically are LeClanche cells. Heavy-duty types may use a high-performance LeClanche system, but they are more commonly based on zinc chloride.

Materials for the LeClanche system are cheaper than those for zinc-chloride cells which, in turn, cost less than alkaline components. Alkaline batteries generally cost less per hour of operation, however, than others where drain current is high and usage frequent. But LeClanche batteries are often the most economical way of obtaining light and infrequent current drain. Zinc-chloride batteries typically cost less per hour than the others where current drain and frequency of use are moderate.

Alkaline cells have higher maximum practical current rates than do zinc-chloride cells. And maximum current in zinc chloride exceeds that of LeClanche. The highest practical rate for typical D cells, for example, is 200 mA/in.^{2} of separator area for alkaline cells and 150 mA/in.^{2} and 100 mA/in.^{2} of zinc area for the other two.

Energy density for LeClanche cells run from 1 to 2 Wh/in.^{3} and from 2 to 2¼ Wh/in.^{3} for zinc chloride. Alkaline cells have about the same range of energy per pound as zinc chloride, but their active materials are heavier. So, energy per unit volume for alkaline cells (2.5 to 4.5 Wh/in.^{3}) exceeds that of any other commonly available cylindrical cells.

Alkaline cells have lower internal resistance and perform better at low temperatures than zinc-chloride cells. And the latter is better in both categories than LeClanche.

The open-circuit voltage of fresh LeClanche batteries is typically about 1.55 V. Zinc-chloride batteries typically exhibit 1.6 V, and alkaline, 1.58 V. And in all the batteries, closed-circuit voltage declines gradually with depth of discharge.

Dry-cell batteries are not rated in ampere-hours because efficiency varies with current drain, operating frequency, temperature, and storage conditions prior to use. And acceptable levels of cutoff voltage vary from one application to another. The efficiency of all three batteries improves as current drain decreases. Thus, where battery efficiency is important, it is generally best to use the largest battery consistent with physical limitations.

Efficiency, moreover, varies from one type of battery to another. Under light current drain, the ampere-hour capacity of alkaline batteries is about twice that of corresponding zinc-chloride types. And capacities of zinc chloride are slightly above those for LeClanche. But at high current drain, the ampere-hour capacity of alkaline can be up to three times that for zinc chloride and ten times that for LeClanche.

For alkaline cells under moderate current drains, duty cycle hardly affects capacity. The capacity of zinc-chloride cells depends only slightly on duty cycle. But up to a point, LeClanche cells experience a rapid drop off in capacity with increasing duty cycle.

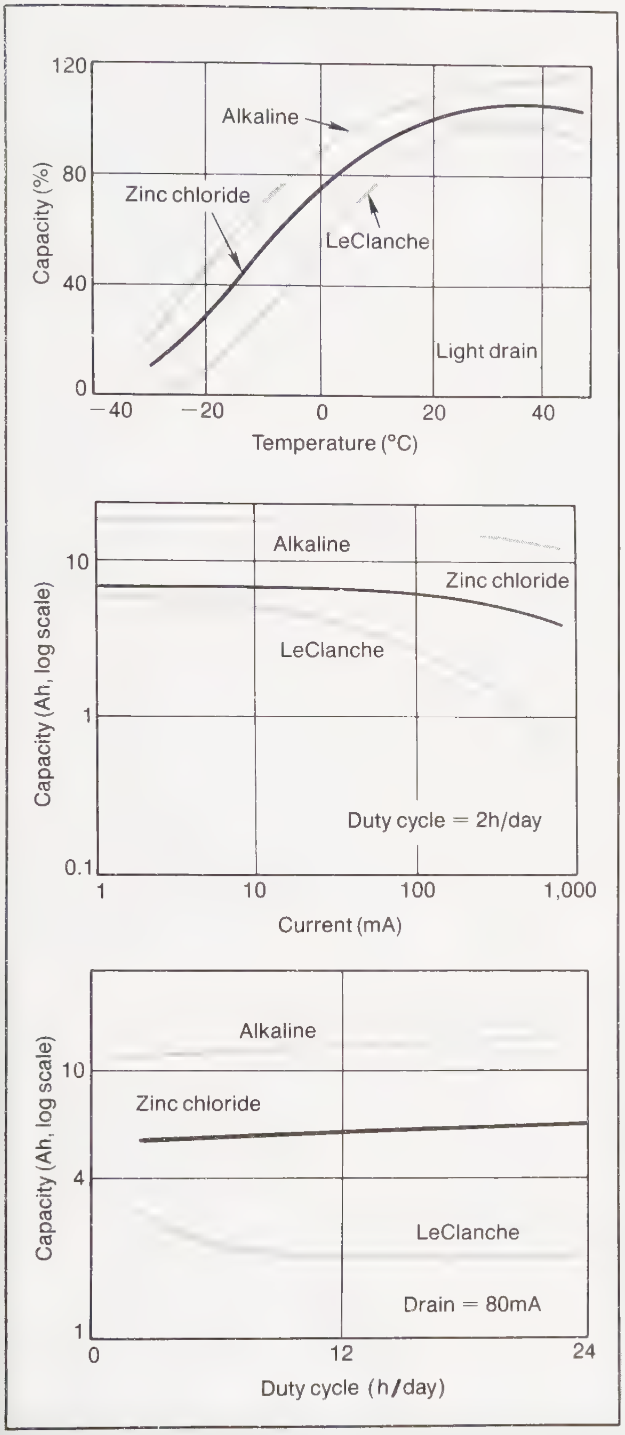
LeClanche and zinc-chloride cells typically retain 90 to 95% of their fresh service life after one year of storage at 21°C. They retain 65 to 75% after four years. But storing the batteries for appreciable periods at temperatures over 21°C significantly reduces their service life.

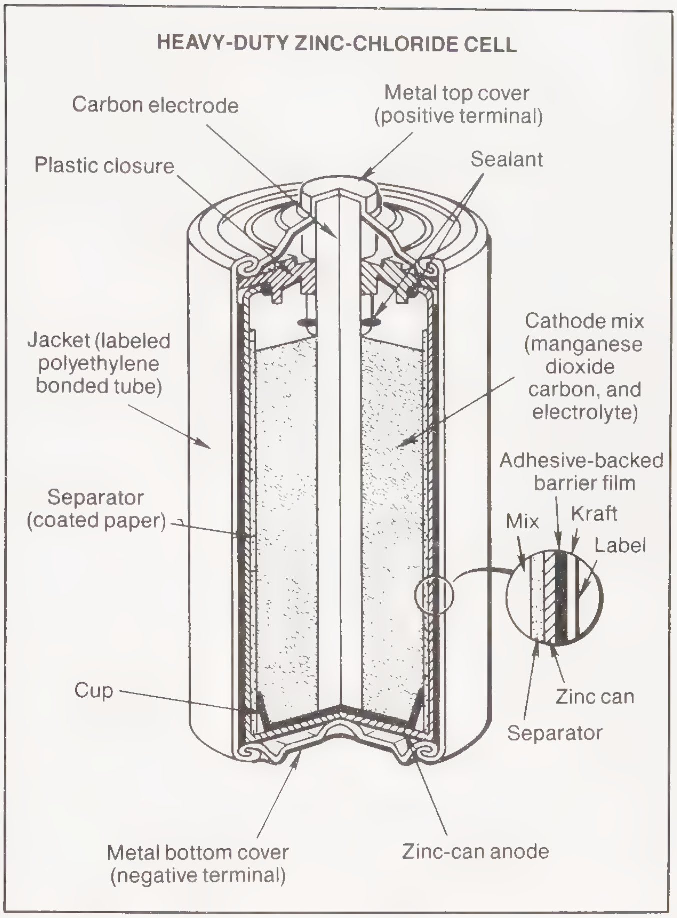
A way to maintain better life, on the other hand, is by storing them at temperatures down to −20°C. For example, batteries stored at 10°C retain 90% of fresh service life for over three years.

LeClanche and zinc-chloride batteries are best kept at low temperatures in their original cartons or wrapped in plastic. When removed from storage, they should remain in the package until they reach room temperature. Otherwise, condensation can cause electrical leakage which reduces life and may destroy the battery case.

Alkaline batteries retain 95% of their fresh service when stored one year at 21°C and 80% after four years. Storage at higher temperatures reduces battery life, but the effect is less severe than in carbon-zinc cells. Storage temperatures below 21°C maximize battery life, but the percentage of life saved generally makes it uneconomical to provide special low-temperature storage.

Miniature alkaline batteries: Alkaline batteries in miniature packages are economical power sources for applications that do not call for the flat voltage discharge characteristic of mercuric and silver-oxide cells. The miniature alkaline cells operate over a wide temperature range, resist shock, vibration, and acceleration, and exhibit low, essentially constant resistance.




HEAVY-DUTY ZINC-CHLORIDE CELL

COMPARING COMMON DRY CELLS

The energy available from different types of dry cells varies with current, duty cycle, and temperature. The accompanying graphs display available energy characteristics for typical fresh D cells operating at 21°C for each of the parameters. In each case, service life ends when output drops to 0.75 V.

The light drain specified in the temperature-effects graph is the level of current that discharges each cell in 50 h at room temperature. Heavier drain decreases service from the percentages defined by the curves. Increasing drain currents affects LeClanche cells the most and alkaline the least.

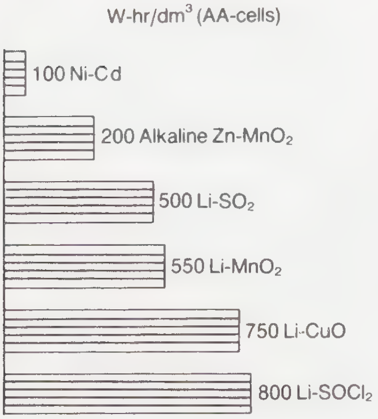
Sensitivity to discharge rate for miniature alkaline cells is comparable to that of silver oxide. Energy density is lower than for comparable mercuric-oxide and silver-oxide cells. Miniature alkalines have a slightly sloping discharge curve and they bulge slightly on discharge.

Lithium batteries: Theoretically, lithium has the highest energy density of any metal. Batteries based on oxidation-reduction reactions between lithium anodes and cathodes exhibit exceptionally long life.

There are several different groups of lithium (Li) batteries. The type of cathode and electrolyte determines their classification. The two basic groups are solid and liquid electrolyte. These further divide into solid and liquid cathode. Additional classifications can be made by subdividing the batteries by chemistry (SO_2, CuO, etc.) or construction (coin, bobbin, or spiral).

The reason for the multiple classifications is that the cathode, electrolyte, and construction determine battery output qualities. Two batteries constructed differently but with the same chemistry will have the same output voltage. However, they will have different discharge curves. Similarly, Li batteries with different chemistries may have similar voltages but different discharge curves.

For example, most commercial Li

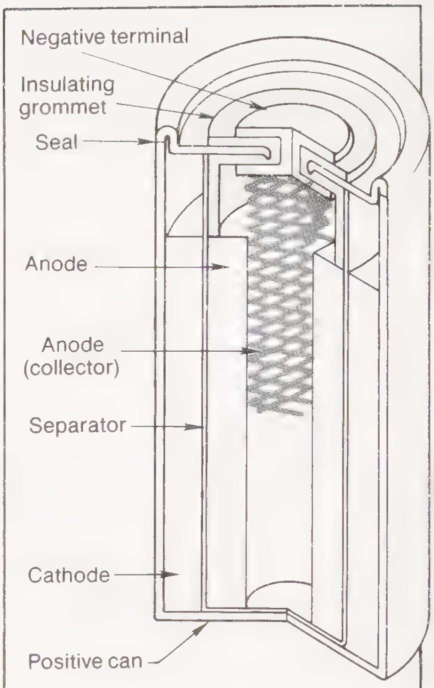


A comparison illustrates the high energy/volume ratios of lithium batteries over nickel-cadmium and alkaline types.

batteries use manganese dioxide (MnO_2) as a cathode. These cells all have an operating voltage of about 2.8 V. But the type of construction used in batteries intended as backup power for computer memories differs from that of batteries used in cameras, though both batteries may be cylindrical in shape.

Memory backup cells must deliver a low current over long periods. A bobbin-type construction makes this sort of operation possible. The anode and cathode are made thick (to store a lot of energy), and the surface area between the two is relatively small. The small surface area limits the maximum current. Bobbin cells have energy densities as high as 700 Wh/L.

Unlike computer memory, cameras demand high peak currents. Therefore, the anode and cathode must have a large surface area. Cells designed either to deliver high pulse currents or for continuous operation typically use a spirally wound anode and cathode. This construction makes the surface area between the two about ten times greater than that in bobbin types. A porous polypropylene separator keeps the two electrodes from directly touching, which would cause a short.



While externally similar to spiral-wound cells, the internal construction of the bobbin type of cell is quite different. Bobbin types have a much thicker anode and cathode, and the surface area between the two is only about one-tenth of a spiral-wound cell. This type of construction stores a lot of energy, but releases it slowly.

Cell chemistry affects more than simply the output voltage. For instance, consider the discharge curves of two spiral-wound batteries with similar voltages but different chemistries, lithium polycarbonmonofluoride ($Li\text{-}CF_n$) and $Li\text{-}MnO_2$. At room temperature (70°F) with an 8-Ω load, the two batteries have similar voltage and about the same lifetime. But at low temperatures (−4°F), the battery made with CF_n only lasts about one-fourth as long as the other.

Some new Li batteries use iron disulfide (FeS_2) for the cathode. The cathode material determines cell voltage. Iron disulfide has two advantages over other cathodes: It is inexpensive and generates 1.5 V.

Other materials, such as copper oxide (CuO) can also be used to make 1.5-V batteries. But Li-CuO batteries exhibit a problem called "voltage up." This refers to the open-circuit voltage of a Li-CuO battery, which is 2.4 V. Once connected to the circuit, the voltage rapidly falls to 1.2 to 1.5 V. But this phenomenon may damage the connected electronics. The problem can be avoided by using FeS_2 for the cathode.

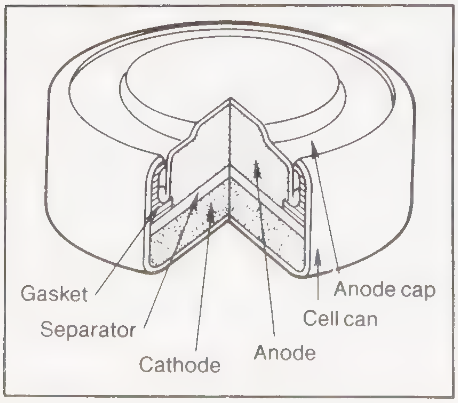
Some batteries can withstand continuous use at a moderate to high current (500 mA or more). Therefore, it has spiral construction. To make the battery, FeS_2 is powdered and mixed with a graphite paste. The graphite increases conductivity. To form the cathode, the mixture is applied to a metal carrier (film).

Batteries are assembled by placing a thin plastic separator between the Li and cathode. Before being rolled, the anode and cathode are about 1.5 in. wide and over a foot long.

Electrolyte is added after the electrodes are put in the can. Like the cathode, the electrolyte determines battery performance.

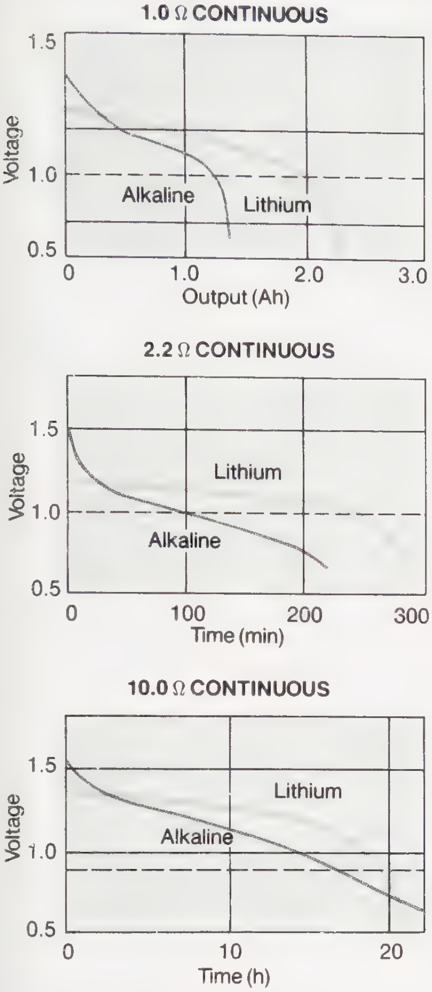
MINIATURE CELLS

Construction of miniature silver, mercury, and alkaline cells is similar and the anodes of all three consist of amalgamated zinc powder and electrolyte. Cathodes in silver cells consist of silver oxide, sometimes mixed with manganese dioxide, and a carbon conductor. Mercury-cell cathodes are mercuric oxide, sometimes mixed with manganese dioxide, and a carbon conductor. Those for alkaline cells are manganese dioxide mixed with a conductive carbon matrix. The electrolyte in all cases is potassium or sodium hydroxide in water.

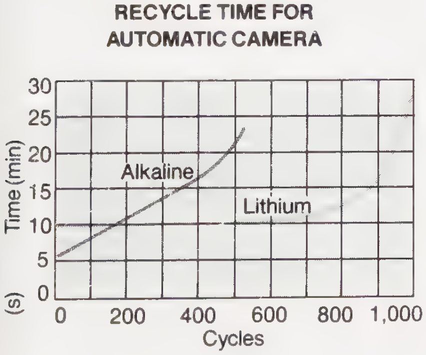


Typical characteristics of miniature batteries

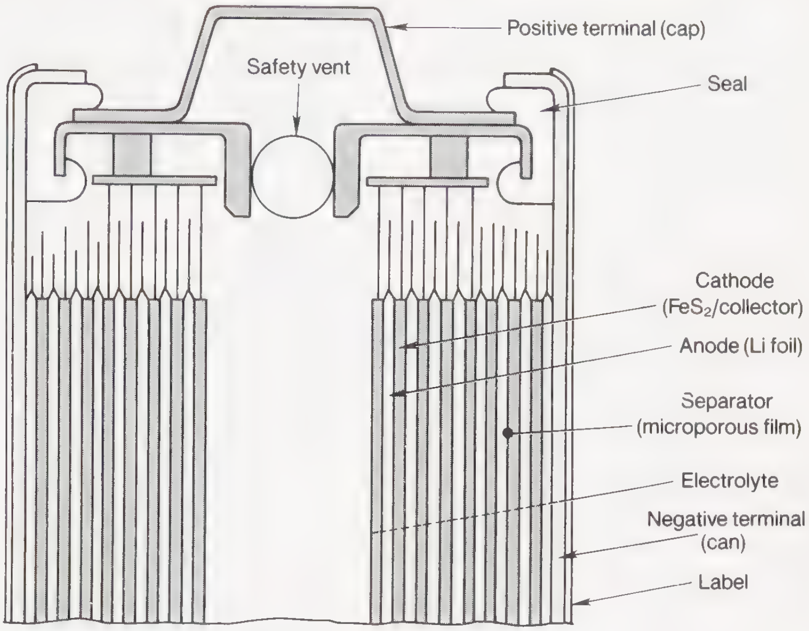
System	Energy density (wh/l)	Mid life voltage (v)	Active shelf (yrs)	Rate capability max. pulse (mA)
Air/Zn	975	1.30	0.3	50
AgO/Zn	678	1.55	5.0	55
Ag_2O/Zn	465	1.55	3.0	55
HgO/Zn	553	1.34	3.0	30
MnO_2/Zn	229	1.31	2.0	30
MnO_2/Li	630	2.80	5.0	5
CF_x Li	520	2.60	5.0	5
FeS_2/Li	440	1.60	5.0	5



The degree to which a lithium battery outlasts alkaline cells depends on the load. In general, as the load increases, the difference in performance decreases.



The initial discharge rate of a 1.5-V lithium battery is initially slower than a comparable alkaline cell. However, the rate of the alkaline cell falls off with just a little use, while the lithium battery's rate remains almost constant.



The major development that led to a 1.5-V lithium battery is the use of an iron-disulfide (fool's gold) cathode. To make the battery, the lithium anode and the cathode are rolled up together. A thin plastic film separates the two. The film allows ion exchange but prevents a direct electrical short. The cell's cap and seal incorporate a positive temperature-coefficient resistor that limits current at high temperatures. The safety vent opens at an internal pressure of about 40 psi.

The electrolyte is aprotic, meaning that it has no reactive protons or hydrogen atoms. However, the electrolyte also has a high ionic conductivity, a quality usually associated with free hydrogen. The electrolyte is relatively nonreactive with Li and is liquid over a broad temperature range. This last attribute is needed to give the battery a wide (−40 to 70°C) operating range.

Mercuric oxide: The zinc-mercuric oxide cell offers more energy density than either C-Zn or alkaline cells. During its service life, between 80 and 90% of the active electrochemical materials are utilized.

The anode is a zinc-mercury amalgam; the cathode, which acts as the depolarizer, is mercuric oxide. Potassium hydroxide is the electrolyte.

A flat voltage-discharge curve and higher than normal sustained voltage under load are other characteristics of the mercury cell. It has a relatively constant ampere-hour capacity regardless of current drain, excellent shelf life, good high-temperature characteristics, and resistance to shock, vibration, and acceleration.

Silver oxide: Like the mercury cell, the silver-oxide primary battery has a very flat voltage-discharge curve. But unlike mercury, it operates at about 1.5 V (1.6-V open circuit). Both mercury and silver-oxide cells have about the same ampere-hour capacity.

The silver-oxide primary battery is best suited for electric watches. The positive electrode is a depolarizing mixture of silver oxide and manganese dioxide which can be varied to tailor the cell to the application. The anode is zinc. For hearing-aid cells (slow drain, long life), highly alkaline potassium hydroxide is the electrolyte, selected to boost energy density; for watches (very low drain, very long life), sodium hydroxide is chosen for longer term reliability at the expense of energy density.

Silver-oxide batteries have excellent shelf life and they operate well at elevated temperatures. At low temperatures, they perform much better than most mercury-zinc cells. Because of the high cost of materials, silver-oxide primary batteries are usually restricted to "button" cells and other small sizes.

Rechargeable batteries: Rechargeable batteries are used to provide backup power for electrical systems ranging from circuit boards to emergency lighting. Most rechargeable batteries are either nickel-cadmium or sealed lead-acid.

Nickel-cadmium and lead-acid batteries are called "sealed" because they lose no electrolyte during normal charging or discharging. Gas generated within the battery is recombined within the cell rather than vented. Both batteries can be charged indefinitely and have low internal impedances (on the order of 10 mΩ) that let batteries deliver rapid high-energy pulses without degrading performance or cell life.

A major difference between the two batteries is cost. For a given energy capacity, nickel-cadmium cells are more expensive than lead-acid cells. But nickel-cadmium are often fabricated with special properties for applications where seal lead-acid cells are impractical. For example, special nickel-cadmium cells can operate at low-temperature extremes. Other nickel-cadmium cells can accept very high charge currents, allowing the battery to charge fully in several minutes rather than hours. Nickel-cadmium cells can also be stored for years in a state of full discharge.

Battery capacity must be evaluated on the basis of temperature extremes. Low temperatures increase internal battery resistance which, in turn, reduces discharge voltage and available discharge current.

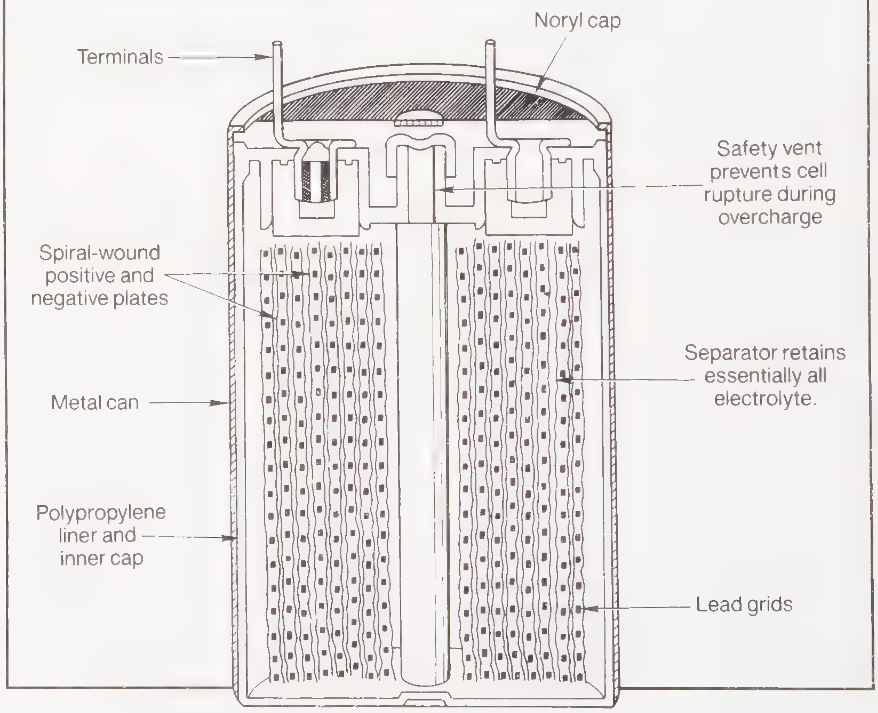
Lead acid: These batteries can be sealed only when they contain limited amounts of electrolyte. Consequently, gases normally generated during charging recombine because they are "starved" for electrolyte. These batteries produce 2 V per cell and lose their charge slowly during storage. Shelf lives of several years at room temperatures are common. However, sealed lead-acid batteries must be stored in the charged state. Otherwise, internal shorts may form in the battery during recharging. Sealed cells may vent electrolyte under extreme overcharging — internal battery pressure builds up to between 30 and 50 psig. However, this condition is rare. In "dry" cylindrical sealed cells, essentially all of the electrolyte is absorbed in the separator so that electrolytic venting does not occur to any practical extent.

Rechargeable cell comparison

Parameter	Nickel-cadmium	Sealed lead-acid
Nominal voltage	1.2V	2.0V
Capacity range	0.065 to 6.5 Ah	2.5 to 25 Ah
Design life		
Standby at 23°C	7 to 8 yr	8 to 10 yr
Full discharge cycles	500 to 1,000	200
25% discharge cycles	Over 2,500	Up to 2,000
Storage life		
Shelf	Indefinite	3 yr (full charge)
Capacity retention	1 to 2% loss/day	0.2% loss/day
Discharge characteristics		
Operating temperature	−20 to + 70°C	−40 to + 65°C
High rate capability	Excellent to 20C	Good to 10C
Internal	8 to 10 mΩ at 2.2 Ah	10 mΩ at 2.5 Ah
Charge characteristics		
Operating temperature	0 to 70°C	−20 to + 65°C
Constant current (24 h)	0.3C A	0.05 to 0.1C A
Constant voltage (24 h)	Not recommended	2.4 to 2.5 V/cell
Standby (float) charge	0.02 to 0.1C	2.3 to 2.4 V/cell
Quick charge	Up to 0.3C	Up to 0.3C*
Fast charge	15 min.*	90% in 1 hr at 2.45 V/cell

*Termination required

CONSTRUCTING A LEAD-ACID BATTERY


Noryl cap
Terminals
Safety vent prevents cell rupture during overcharge
Spiral-wound positive and negative plates
Separator retains essentially all electrolyte.
Metal can
Polypropylene liner and inner cap
Lead grids

Another kind of sealed lead-acid cell uses gelled electrolyte. These rectangular batteries have flat rather than cylindrically wound plates, and they vent at pressures of only 2 to 5 psi, unlike cylindrical cells. Although these batteries can be operated in any position, manufacturers often recommend they be mounted upright so the electrolyte makes good contact with the plates and to minimize the chance that electrolyte is vented during charging (vents are on the battery top).

Although gelled-electrolyte batteries cost less than comparable cylindrical lead-acid batteries, working life is shorter. Moreover, most manufacturers recommend against fast-charging these cells. Gelled-electrolyte capacity at low temperatures is also somewhat less than that of cylindrical sealed lead-acid or nickel-cadmium cells.

Nickel-cadmium: Nickel-cadmium rechargeable batteries are sealed, packaged in cylindrical cases, and incorporate a wound plate and separator structure. Nickel-cadmium cells can be recharged at high rates, in as little as one to three hours under certain conditions, and have inherently low internal resistance that allows them to power high-current or pulse-current applications. Standard cells can operate up to

120°F and premium cells to 158°F. Five to ten-year standby life is common over 300 to 1,000 charge-discharge cycles.

Nickel-cadmium batteries are also available in button cells. Button-cell devices are generally suitable for low-current applications where the chance of overcharging is minimal. Capacities range from 20 to 500 mA-h.

Nickel-cadmium battery voltage increases during charging, then decays slowly during discharge, providing a relatively flat voltage-discharge curve. Cell capacity depends on discharge rate, the voltage at which discharge is terminated, discharge temperature, and previous battery history. For example, the average battery voltage during discharge decreases as the discharge rate increases. Temperature extremes also tend to diminish capacity.

Nickel-cadmium batteries can sometimes go through cell reversal when cells are connected in series. Here, the lowest capacity may be driven into reversing polarity if it fully discharges first. The more cells in the battery, the greater the chance of cell reversal.

Typical nickel-cadmium positive and negative cell plates are made of sintered nickel powder. This process produces a porous structure that is about 80% open pores with surface area of about 0.2 m^2/gm. The pores are par-

HOW TO CHARGE LEAD-ACID BATTERIES

Improper charging of a lead-acid battery can shorten battery life. To avoid damage, batteries must be charged at specific levels of current and voltage.

Too much or too little charging voltage can damage the battery. An excessively high charging voltage forces a high current into the battery, even after it is fully charged. This high current decomposes the electrolyte and causes premature battery aging. Conversely, a low charging voltage allows charging current to stop before the battery is fully charged. As a result, some lead sulfate remains on the battery plates and eventually reduces battery capacity.

Most lead-acid battery-charging circuits incorporate a current-limiting mechanism (usually a resistor). Some severely discharged batteries draw large currents when first connected to the charger. Without current limiting, the initial charge current may exceed the charger capacity. As the battery charges and its terminal voltage increases, it accepts less current.

Chargers are either taper current or regulated. Taper-current chargers are generally less expensive but not usually recommended. They force a constant current into the battery, even as the battery terminal voltage increases with charge. Unfortunately, the battery must accept the charge current even if it is fully charged. Thus, a high trickle current causes premature battery aging unless the battery is disconnected when fully charged.

Typically, a taper-charge circuit consists of a transformer and diode rectifier. The transformer reactance serves as a current limiter because it causes low output voltage when the discharged battery first accepts large currents. As charge current decreases, charger output rises.

The taper-charge transformer is selected to supply a specified trickle current. A transformer so chosen can generally supply starting charge currents five or six times that of the eventual trickle currents.

Regulated chargers, though generally more expensive, are more widely used than taper chargers. Regulated chargers provide nearly zero charge current when the battery is fully charged. This, in turn, prevents the battery from overcharging.

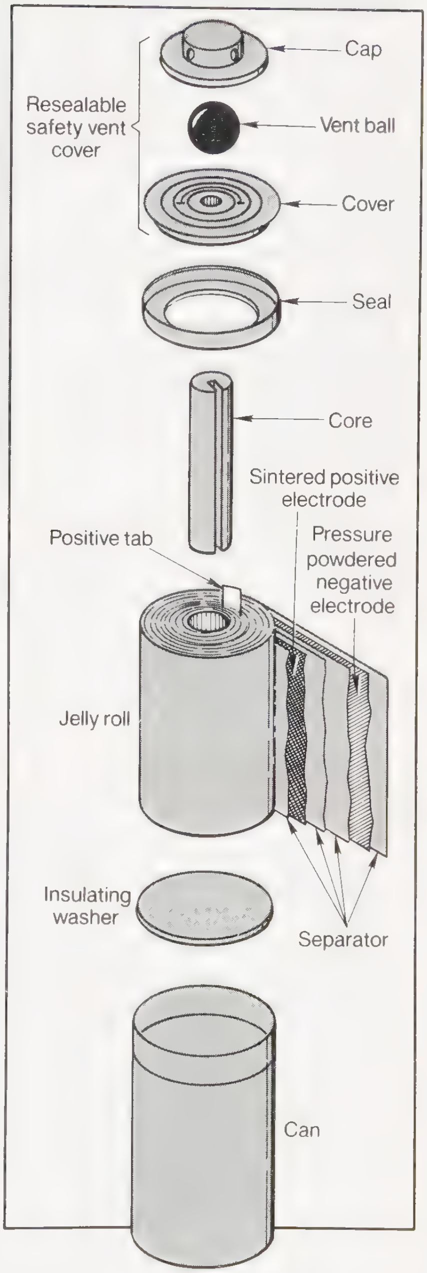
The simplest regulated charger consists of a current-limiting resistor in series with a rectifier, and a Zener diode in parallel with the battery. The Zener forces a constant voltage across the battery.

Simple regulator circuits are generally adequate for 6 to 12-V batteries and maximum charge currents of up to several hundred milliamperes. A high-power transistor can be connected in series with the battery to regulate high voltages and currents. This transistor often requires a small transistor to regulate its base voltage. A Zener is placed in the base or emitter circuit of this small transistor to set the charging voltage.

Some batteries charged in series require other precautions. Individual battery cells often have slightly different terminal voltages because of such factors as age or temperature variations. As the number of cells in series increases, the possibility for cell differences also increases. But a charger supplies the same current to all cells. Consequently, some cells may overcharge while others may slightly undercharge, depending on individual cell characteristics. To minimize these effects, batteries should be nearly the same age and not installed near hot spots such as heat sinks or power resistors. A resistor voltage divider can also be placed across several batteries in series to even battery voltages.

NiCd CELLS

Cathodes of nickel-cadmium cells are nickel hydroxide supported on a metal carrier. The anodes are a mixture of cadmium oxide and cadmium hydroxide on a metal carrier. Electrolyte for the cell is a highly conductive, low freezing-point solution of potassium hydroxide in water.


Resealable safety vent cover
Cap
Vent ball
Cover
Seal
Core
Sintered positive electrode
Positive tab
Pressure powdered negative electrode
Jelly roll
Insulating washer
Separator
Can

FORGET THE MEMORY EFFECT

The infamous label "memory effect" has haunted nickel-cadmium cells since the mid 1960s. It was originated to describe a phenomenon observed in the power system of a U.S. satellite. The memory effect implies that a nickel-cadmium (NiCd) cell can forget how to deliver all of its charge if continually partially discharged to the same level. In other words, if a rechargeable 2-h battery runs 5 min each day, it will turn into a 5-min battery.

Memory effect seems to be brought on by certain conditions. First, the battery must be designed with cell cutoffs above 1 V. Second, it must be repetitively discharged to about the same shallow level. Third, it must receive no overcharge. If the three conditions are satisfied, then there is a remote chance of permanent loss of some capacity.

Since the mid 1960s, memory effect has been the "cause" of almost every conceivable rechargeable-product malfunction. To avoid it, fearful users have vigilantly enforced complete discharge of the battery on each cycle. But in reality, memory effect has been officially diagnosed in only that one instance in outer space. The overuse of the term may be a case of confusing memory with a similar phenomenon called "voltage depression."

Voltage depression refers to a drop in NiCd discharge voltage. It it caused by a combination of poor design and product misuse which lowers anode oxidation efficiency during discharge. Again, cutoff voltage must be above 1 V. In this case, however, the battery must excessively overcharge for extended periods of time. When these conditions coincide, products may experience voltage depression which, like a high cutoff, reduces runtime.

Voltage depression was somewhat of a problem with early NiCd cell technology of the late 1960s. It was common with improperly applied batteries made with primitive electrode technologies of that time. Modern electrode technology, however, has nearly eliminated the problem.

The ability to prevent voltage depression is in the hands of designers. Keep the cutoffs below 1 V, and the effect will not be noticed. Users could help by varying the depth of discharge or runtime occasionally. But voltage depression is practically a nonissue because it is completely reversed after the first duty cycle. If it does occur, it shortens only the first run.

C-RATE RELATES CELLS OF VARIOUS SIZES

Of all the rechargeable-battery jargon, *C*-rate may confuse more engineers than any other term. But it is actually a simple concept. *C* is used to specify charge and discharge rates. It is defined as the current flow out of or into a cell numerically equal to the cell's rated capacity. For example, the *C*-rate of a 1-Ah cell is 1 A. Likewise, the *C*-rate of a 2.5 Ah cells is 2.5 A.

C is useful because it makes different-size cells comparable on the basis of scaled charge/discharge rates. Within a product type, cells behave similarly in terms of voltage and runtime when charged or discharged at the same *C*-rate. For instance, a 1-Ah cell supplying 0.1 A and a 10-Ah cell delivering 1 A both discharge at a rate of $0.1C$. Both cells have the same runtime of 10 h, and both cross midpoint and cutoff voltage concurrently.

Several cautions should be taken when comparing cells using *C*. Cells must be rated according to the same cycle time for valid comparison. Nickel-cadmium cells may be rated based on 1 or 5-h cycles while sealed lead-acid cells may be based on 10 or 20-h cycles. A 1-Ah rating based on a 1-h cycle is much different than a 1-Ah rating based on a 5-h ($0.2C$) charge/discharge cycle.

Cells drained more slowly have a lower effective internal resistance and a higher efficiency discharge. Thus, they deliver a larger percentage of their total capacity. This makes them look better on paper.

Another pitfall is that *C* scaling begins to lose accuracy at high rates in excess of $10C$. At these rates, cell behavior is highly sensitive to application variables such as duty cycle and load circuit.

Nickel-cadmium cell recharge rates

Method of charging	Charge rate (C-rate)	Recharge time (h)
Standard	C/20	36-48
	C/10	16-20
Quick	C/5	7-9
	C/4	5-7
	C/3	4-5
Fast	C	1.2
	2C	0.6
	4C	0.3
Trickle	C/10-C/50	*

*Maintains charge of a fully charged battery.

tially impregnated with an active material, with some of the remaining space being left for the electrolyte.

The active material in an uncharged positive plate is nickel hydroxide. Upon charging, this material becomes nickelic hydroxide. An uncharged negative plate contains cadmium hydroxide, which is converted to metallic cadmium by charging. The polarity of a plate is, thus, determined by the chemical used for impregnation.

Battery holders: A variety of battery holders, some suitable for PCB mounting, are available for carbon-zinc, alkaline, and lithium batteries. Included are types having pressure terminals for ⅔ A, ¼ AA, AA, and C batteries and others with male and female snap fasteners for 9-V units.

Batteries are also available with tab terminals suitable for soldering directly to PCBs. ■

Indicators and displays

Solid-state devices rival traditional incandescent lamps and CRTs in terms of brightness and resolution.

Displays and indicators cover a wide range of functions. Incandescent lights provide warnings and highlight pushbuttons on control panels. Light-emitting diodes (LEDs) provide on/off signaling and illuminate alphanumeric readouts. Liquid-crystal displays (LCDs) have an advantage because of their low power drain and custom display ability. Cathode-ray tubes (CRTs) are often used in computer terminals for readouts and large data displays. And electroluminescent displays are coming on strong.

Indicators

Incandescent miniature and subminiature lamps are used in applications requiring high brightness, a wide viewing angle, and a variety of display colors. Incandescent lamps generally provide between 6 and 50,000 mcd (millicandellas), while LEDs generally produce between 1 and 40 mcd. Neon lamps typically produce 5 to 12 mcd per milliamp.

Incandescent lamps are sensitive to voltage, shock, vibration, and cycling frequency. A 5% rise in lamp voltage above design level reduces service life by 50%. Many lamp manufacturers state that lamp life varies inversely as the twelfth power of voltage.

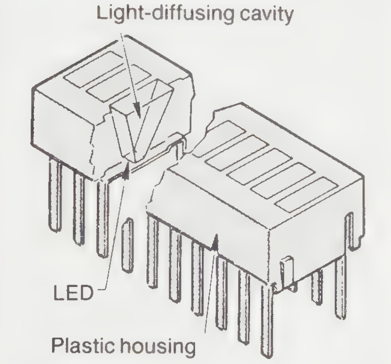
These manufacturers suggest using low-voltage filaments, which are short and rigid and have inherently high mechanical resonant frequencies. This helps soften shock and vibration.

Incandescent lamps are also sensitive to flashing rate, especially with high-energy bursts. High peak voltages and temperatures can damage the filament. In addition, flashing rates near the filament mechanical resonant frequency can couple thermal energy into the mechanical system and produce vibration.

At low on/off frequencies, inrush currents shorten lamp life. Inrush currents in lamps operating at room temperature can be as high as 12 times normal operating current and can last 20 to 40 ms. At high frequencies, on the other hand, light filaments cool little between flashes and resistance stays high, causing much lower inrush currents.

Miniature lamps: Miniature lamps consist of incandescent lamps, neon lamps, and halogen-cycle lamps.

Artificial light is usually produced by passing an electric current through a coil of tungsten wire. A miniature incandescent lamp consists of a bulb with lead wires soldered to a metal base that fits into a socket. The entire assembly has about ten parts including the lamp, metal base, and all the socket components — contacts, terminals, springs, clips, and insulators. However, a wedge-base design eliminates the metal base and complicated socket. In this design, the bulb snaps into a metal clip that mounts in a one-piece, molded-plastic socket. The assembly is made up of only three parts. Also, the solid glass portion at the bottom of the bulb is longer to reinforce the lead wires. The glass is extra thick, grooved, and wedge shaped to reinforce and orient the bulb in the socket.



Bar-graph arrays with 10 to 15 LEDs typically have leads on 0.1 × 0.3-in. centers for PCB mounting. The arrays are stacked end to end where greater resolution is required.

Minimum lamp-space requirements allow the end product to be more compact, especially in applications using printed-circuit boards. The simple push-in motion of installation is readily adapted to automatic assembly equipment. Wedge-base lamps have been used successfully in vibratory bowl feeders.

Lamps may operate in high ambient temperatures because they contain no metal base or soldered connections. Most wedge-base lamps can be operated in ambient temperatures up to 230°C, compared to a limit of 175°C for conventional metal-base lamps.

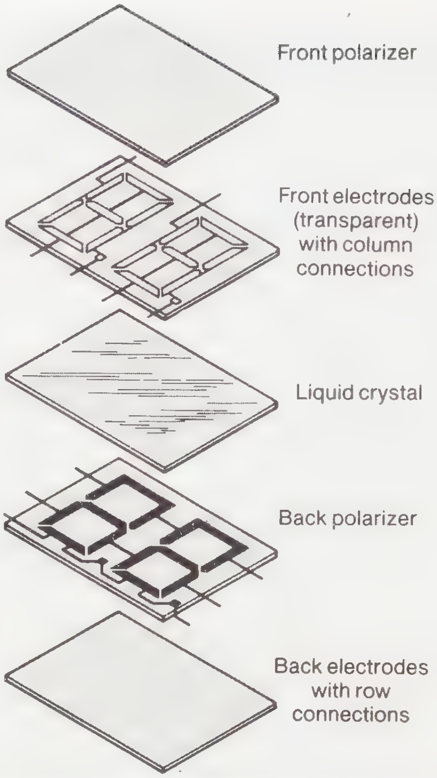
Halogen-cycle lamps are often used where size and space are limited. These lamps differ from incandescent lamps primarily in the gas fill within the bulb. In an ordinary incandescent lamp, tungsten from the hot filament boils off and deposits on the inner wall of the bulb. Over a period of time, the bulb wall blackens, light output decreases, and the filament narrows and weakens. In contrast, a halogen-cycle lamp contains a halogen vapor (such as iodine) in addition to the normal gas fill. This halogen vapor combines with the boiled-off tungsten particles and continuously redeposits the tungsten back onto the filament. Thus, lamp life is increased while light intensity remains virtually constant.

Neon lamps: Neon glow lamps combine functional indication with the aesthetics of color illumination. Glow lamps have two electrodes sealed inside a glass envelope containing a gas, typically neon. When enough voltage is applied, current flows through the gas, ionizing it and causing it to glow near the negative electrode.

Color glow lamps offer several advantages over incandescent miniature and subminiature lamps. In-line operation permits direct connection to 110/120 and 220/240 Vac or dc line voltage with appropriate resistors. Low power consumption means that a neon lamp requires only 0.2 W, compared to 1.5 W for an incandescent lamp.

Brightness can be improved by increasing current levels. Color glow lamps can be operated at up to 3 mA to double brightness. Cool operation allows the lamp to be located near heat-sensitive components without any adverse effect. Good shock and vibration resistance results from the absence of a filament. Rated average life of color glow lamps exceeds 30,000 hr.

LED indicators: LED indicators are employed when incandescent lamps give off enough heat to damage nearby equipment. In addition, LED


Front polarizer
Front electrodes (transparent) with column connections
Liquid crystal
Back polarizer
Back electrodes with row connections

In the off state, a liquid-crystal molecule is twisted. Light entering the top polarizer is rotated by the molecule, allowing it to pass through the bottom polarizer and be reflected back. An electric field straightens the molecule. This causes light passing through the first polarizer to be absorbed by the second.

In matrix addressing, each drive line controls several display segments. The front and back electrodes are often given different shapes to form a full complement of characters and letters. Most calculator displays, for example, are organized as matrices with three or four rows.

operating life is much longer than that of incandescent lamps. LEDs never burn out under normal use, they merely grow dimmer.

LEDs are generally rated for operation at room temperature. Operating at higher temperatures can cause light intensity to drop to 75% of the rated output. Continuous operation at high temperatures reduces light output at accelerated rates. However, LEDs often operate at low temperatures that would make incandescent lamps fail — when incandescent lamps are turned off at low temperatures (around −50°C), the glass envelope can crack from rapid cooling.

LED indicators generally require a series resistor to limit current. When operating from ac sources, LEDs sometimes require an additional diode in series with the resistor to limit reverse breakdown voltage. LED breakdown voltage is typically from 3 to 6 V.

Unlike incandescent lamps, where light spreads out uniformly in all directions, LED light radiates almost entirely straight ahead. Manufacturers generally provide beam patterns for specific LED styles because light patterns vary greatly by package type. Lenses are also available for inclusion on LED packages to modify light output patterns.

Electronic bar-graph displays, arrays of LEDs molded in a common package, are widely available. Bar graphs can be powered by standard ICs called array drivers. The general technique is to drive arrays by converting analog, binary-coded decimal (BCD), or binary signals to decimal form. Displays can also be microprocessor or computer controlled.

To drive bar graphs from analog signals, LEDs are generally powered by standard analog bar-graph array drivers. These ICs are nothing more than analog-to-digital (a/d) decoders with sufficient output to drive LEDs. They can be fed directly from most analog transducers without intervening amplifiers or other signal conditioning. Analog array drivers have 5 to 16 outputs and are cascaded to accommodate large LED arrays.

Improved LEDs: At one time, watch and calculator LEDs were made of GaAsP. Often referred to as standard red, these devices emit light at a wavelength of 655 nm. Although GaAsP is still used in low-end displays, today's technology offers displays that are considerably brighter. In the mid 1970s, so-called high-efficiency devices (GaAsP:N) were commercially introduced. A mixture of GaP, rather than GaAs is used for the substrate. One reason efficiency is improved is because GaP, unlike GaAs, is transparent. Color is determined by the ratio of As to P and doping of the epitaxial layer. Available colors are red (635 nm), yellow (583 nm), and yellow-green (566 nm).

In the early 1980s, manufacturers began offering devices doped with a liquid-phase epitaxial process. The advantage is that the resultant LEDs have a higher efficiency than those doped with a conventional vapor-phase process. When used with a GaP substrate, an extremely bright device results.

When these LEDs are coupled with an antireflection, circular-polarized filter, they provide sufficient luminous contrast to meet military requirements for sunlight readability. In 10,000 fc ambient light, a luminous contrast ratio better than 2.0 is possible. The displays are available in yellow-green (566 nm) and emerald green (555 nm).

LEDs offering the highest efficiency use AlGaAs and a transparent substrate. These devices typically produce infrared wavelengths in the 800-nm region.

Although blue LEDs have been available for several years, many of the manufacturing bugs have only recently been ironed out. Several semiconductor materials were initially investigated, including ZnS and ZnSe. The problem with these materials is that they produce high-resistance *p-n* junctions. Therefore, they need relatively high operating voltage to operate efficiently.

Several LED makers have turned to SiC to circumvent this problem. Although SiC has a bandgap that is less efficient for light generation than the other materials, it is easily doped. The result is an LED that emits blue light (480 nm) with an average luminous intensity of 6.0 mcd.

Flat-panel displays

Designers looking for flat-panel displays a few years ago had limited choices. In general, flat displays were small, had poor contrast and resolution, and were difficult to interface with ancillary electronics. But liquid-crystal displays (LCDs), electroluminescent (EL), and plasma displays have greatly improved. The features that flat-panel displays provide — low volume and light weight — have been augmented by larger screen areas, better contrast, and improved drivers and interfaces.

Work in LCDs has been particularly extensive. The driving force is threefold: The devices are inexpensive, the technology is relatively well known, and there is a broad consumer market for LCD panels. LCD manufacturers are now trying to improve display qualities such as contrast, viewing angle, and resolution.

LCD researchers are using what are called active panels to improve these characteristics. An active panel consists of a thin-film transistor or diode that is used to drive a pixel. The advantage of these devices is that they improve a display's response time and contrast. However, questions concerning the optimal transistor configuration and how to decrease manufacturing cost remain unanswered.

Liquid crystals: Liquid-crystal displays (LCDs) are helping manufacturers meet consumer demand for smaller, more portable products. LCDs draw less current and run on lower voltage than conventional displays made of light-emitting diodes. The also are more difficult to drive because they rely on complex chemical properties.

LCDs consist of liquid crystal sandwiched between polarizing glass plates. Liquid-crystal molecules are elongated in shape and align themselves to external electric fields. Molecular orientation determines how the material reflects light. Display segments are made "visible" or "invisible" by electrically aligning localized molecules to the polarizing plates. Voltage is applied across electrodes on the front and back planes of the assembly.

Liquid crystal operates best under alternating electric field. Although a single-ended dc field is easier to generate, it can electrically disintegrate the crystal and shorten the display's life. A time-varying differential voltage applied across the electrodes, on the other hand, preserves the crystal and the display. Most commercial drivers produce these signals.

One way microcontrollers drive LCDs is through a multiplexed interface. This method is suited for displays comprising a large number of segments in matrix arrangement. However, it requires a complex circuit that generates several intermediate voltages to safely control display segments. Commercial LCD drivers for medium to large displays commonly provide this function.

If the display has only a few characters, an easier way to control it is with a static drive. This method involves individual connections to each display segment, and it eliminates the need for an interface IC. Static drive is similar to the control method used for seven-segment cathode displays. It employs a common backplane driver and individual segment drivers for the electrodes on the front plane. The interface is easily derived from the TTL logic or microcontroller input/output.

To protect the display, an alternating voltage continuously changes the electric potential on the backplane. Segments are turned off by matching the voltage on the front plane to that of the backplane, while applications of an opposite voltage turn the segment on. Refresh rates are usually set between 30 and 120 Hz, depending on the specification.

Most high-density, high-contrast displays employ a type of liquid-crystal molecule that is often said to be "supertwisted." All liquid crystals exhibit some degree of twist. The amount of twist, and how the molecule responds to an electric field affects its optical characteristics.

Many LCDs that are not highly multiplexed use the so-called twisted nematic effect. The liquid-crystal material is between two sets of polarizers and electrodes. Each polarizer is 90° out of phase with the other. Inactivated liquid-crystal molecules have a 90° twist; activated crystals are straightened by the electric field. The degree to which a crystal straightens is a function of the field strength or activation voltage.

When the display is off, light passing through the first polarizer is twisted 90° by the liquid crystal. This allows the light to pass through the second polarizer. But an activated display does not rotate the light. Light passing through the first polarizer is at right angles to the second polarizer, and is therefore blocked. In large displays, the liquid crystals are used to form lines of dots. Multiple lines form a dot matrix. To address the thousands of dots that form a display, a multiplexing scheme is used.

The number of lines that can be directly multiplexed is limited. The problem is that as the number of addressed

HOW TO DRIVE AN LCD

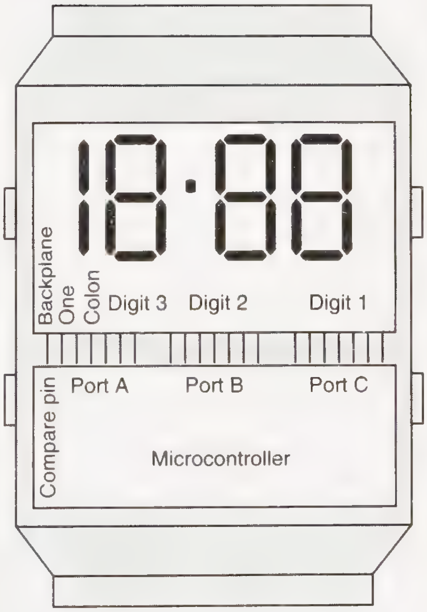
Interfacing microcontrollers to LCDs is simple. Several I/O pins are allocated to individual display segments, while a separate pin drives the backplane. A three-digit display, for example, requires 22 pins, 21 for the segments (3 × 7) and one for the backplane. The software that controls the display must keep track of the polarity of all 22 pins to ensure all segments are in the proper state. Each segment (pin) is controlled relative to the alternating voltage on the backplane.

A periodic interrupt is generated inside the microcontroller (MCU), telling the CPU to invert all front and backplane signals at the specified rate. Since I/O is typically arranged in 8-bit ports, some segments may be inverted before others or even before the backplane. However, the effect does not visibly change the display because LCDs respond slowly.

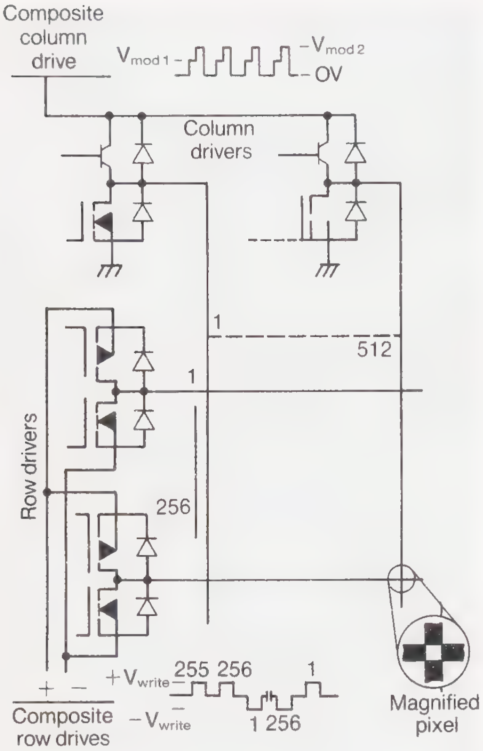
In the case of a 60-Hz display, a timer inside the MCU generates periodic interrupts every 8.33 msec. A timer service routine toggles the backplane pin at 60 Hz and correspondingly inverts data on the front-plane I/O pins to maintain their state.

A timer output-compare pin drives the backplane electrode. Timer hardware compares data in the output-compare register with the contents of a 16-bit free-running counter. When a match is found, the interrupt service routine inverts all I/O pins and reinitializes the output-compare register. The process repeats every 8.33 msec. A separate routine controls segment voltage relative to the backplane voltage, depending on whether the segment is supposed to be on or off.

KEEPING TIME WITH AN MCU



Microcontrollers easily operate small LCDs through a static-drive interface, where each electrode is controlled individually. A 3½-digit watch display, for example, requires just 24 connections, one line each for the colon, backplane, and ½ digit, and 21 lines for the full-digit segments. In a typical microcontroller, the pins are arranged in three 8-bit I/O ports.



FETs are used to drive EL rows and columns. The column composite signal is notched to decrease power consumption. Standard CRT signals can be used to drive the displays. TTL versions are also available.

lines increases, the rms of the activation voltage available for each pixel falls off dramatically. For example, for a 100-line multiplexed display, the rms voltage for a selected pixel is only 10% greater than an off pixel. Consequently, the crystal does not twist very much, and a narrow viewing angle results.

Several methods are used to solve this problem. One involves subdividing the dot-matrix display into two or more smaller ones. For example, a single 640 × 400 display may be addressed as two 320 × 400 displays. While this technique provides a considerable increase in optical performance, it comes at the cost of increased drive circuit complexity.

A second, and perhaps more elegant, solution is to increase the steepness of the liquid-crystal brightness vs. voltage curve. This curve is a function of how far the optical angle of the crystal tilts for an applied voltage. To increase the amount of tilt, several liquid-crystal parameters can be changed. Decreasing the crystal bend/splay elastic constant ratio, or the dielectric parameter $\gamma = \sigma\epsilon/\epsilon_{normal}$ increases the tilt. But even more dramatic results can be obtained by increasing the crystal twist angle from 90 to 270°. This degree of twist makes the slope of the optical tilt angle vs. voltage curve become infinite. At twist angles larger than 270°, hysteresis becomes apparent. Crystals with a large degree of twist are often referred to as supertwisted.

Using a backlight dramatically improves the visibility of LCDs, even when ambient light is good. But backlighting can also significantly increase display cost.

Electroluminescent: There are two different types of EL displays, thin film and thick film. In both types, a phosphor emits light in the presence of an electric field. The monochrome phosphor is a blend of ZnS:Mn, which emits amber light. There are significant differences between the two EL types, including manufacturing techniques, optical qualities, and display lifetime. Driving waveforms are also different.

In thin-film displays, the light-emitting layer is only about one-half micron thick; total thickness of the phosphor and conductors is about 1 μm. Driving voltages are ac. On the other hand, thick-film displays have a phosphor layer about 25 μm thick and use dc voltages.

TFEL displays also contain layers of electrodes and insulators. Manufacturers are constantly seeking ways to improve these components because of their effect on the display's optical characteristics and life.

The electric field of a thin-film display is about 2 MV/cm. Because of the high field any phosphor imperfection causing a short circuit between the electrodes can destroy the device. This possibility is prevented by current-limiting layers (insulators) sandwiched between the phosphor and electrodes.

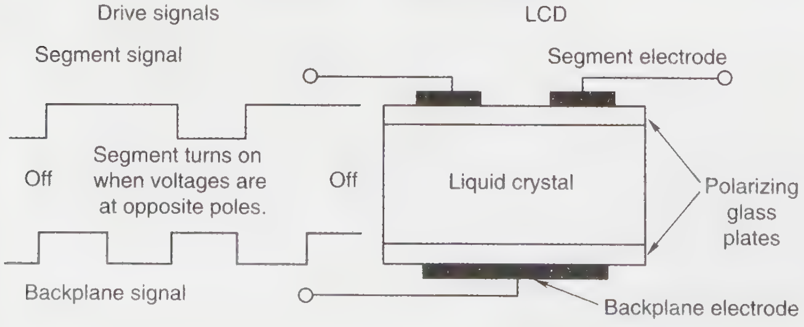
On one side of the phosphor, both the insulator and electrode are transparent, allowing light through to the viewer. The insulator is one of the keys to display performance and reliability. Different manufacturers use different materials, usually an oxide of Al, Ti, Si, or Y, although BaTaO compounds are also used. The best insulators are insensitive to moisture and adhere well to the electrodes. Indium tin oxide (ITO) commonly forms the electrodes. Because ITO cannot handle high currents, driving voltages must be high (about 200 V) instead. Together, the phosphor insulators and electrodes form a capacitor in both thin and thick-film displays.

Ac TFEL devices perform better than dc thick-film displays in several ways. One is useful life. While dc devices work for about 10,000 h, ac TFEL displays have a mean time to failure of about 40,000. The reason ac devices have a longer life is that ac inhibits phosphor migration and breakdown.

One difference of dc EL displays is that they are screen printed, making them simpler to produce. Ac TFEL fabrication uses a photolithographic technique similar to that used to make integrated circuits. Photolithography provides finer resolution than screen printing.

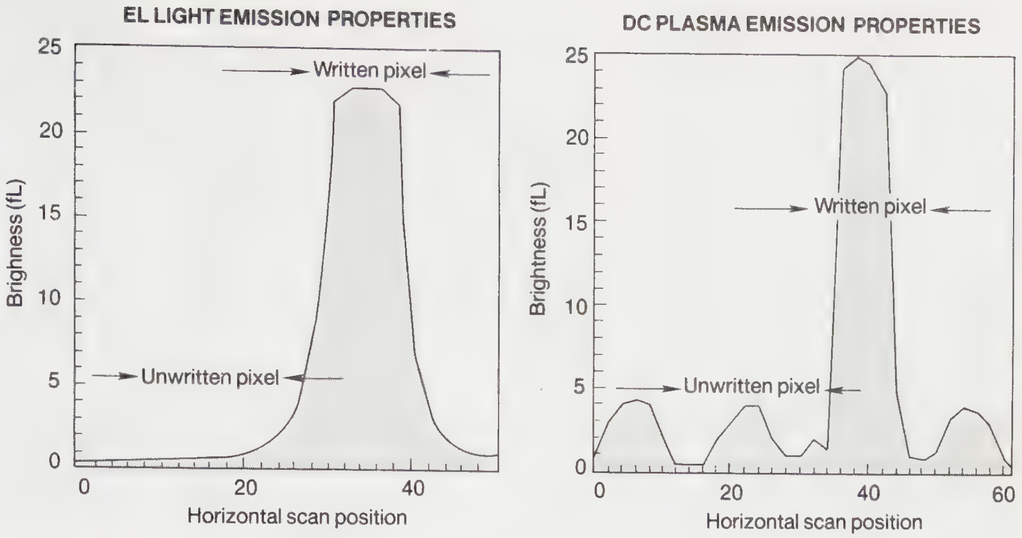
The most important factor determining the viewability of any display is its contrast ratio. Contrast ratio is the *on* brightness of the display (the amount of light emitted) divided by the *off* brightness. The larger the contrast ratio, the easier the display is to read. Generally, a contrast ratio greater than

A SAFE WAY TO DRIVE LCDs



One way to control an LCD while protecting the liquid crystal is to apply an alternating signal to the backplane electrode. Display segments are activated when their drive voltage is of opposite polarity compared to the backplane signal. The differential voltage across the liquid crystal sets up an electric field that changes the crystal's optical properties.

While the emission curve of CRTs and plasma displays is Gaussian, EL-display curves are more rectangular. The rectangular curve, which is better, is primarily due to well-defined EL pixel edges. The contrast ratio of EL panels is also superior because turned-off pixels have a low level of emissivity.



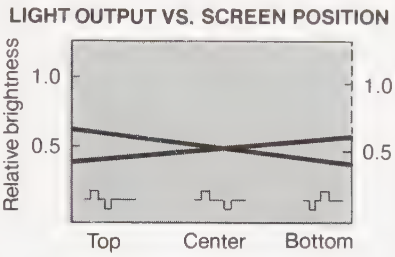
seven is recommended for full and half-screen displays used in a 500-lux ambient. Typical indoor work ambients range from 250 to 1,250 lux.

Other parameters affect display brightness and, hence, contrast ratio. Fill factor is one. It is determined by dividing the display's total area by its lit area. Fill factor is always less than one because there are spaces between individual pixels. Fill factor is an important consideration when choosing a display because the eye integrates brightness over the total display area. For example, if an individual pixel has a brightness of 25 fL, but the display fill factor is only 25%, the display only has an average brightness of 6.25 fL.

Most manufacturers quote pixel, not average display brightness. The waveform used to drive an EL display also significantly affects brightness. In both thin and thick-film EL displays, brightness is proportional to drive voltage, pulse width, and frequency.

Plasma displays: Plasma-based devices are one of the most widely used types of flat-panel displays. Plasma devices have proven to be reliable, provide high density and resolution, and have good viewing qualities. Most commercial displays have luminance between 10 to 100 fL, a viewing angle of about 120°, and contrast ratios of 20:1 or better. Additionally, they have a lifetime of about 20,000 hr, which is considered long. The disadvantages of plasma displays are their low luminous efficiency and high operating voltage.

The basic construction of a plasma display consists of rare gas (for example, argon or neon) sandwiched between two electrodes. When the potential between the electrodes increases to a threshold voltage V_T the gas begins to glow. The gas continues to glow even when the potential drops from V_T to a lower potential called the sustaining voltage V_s. This quality has generated a great deal of interest in plasma displays because it reduces display memory requirements. A pixel is turned on by addressing it with the difference $V_W = V_T - V_S$, where V_S is the potential of a strobe signal applied to the display. After V_W is removed, the pixel continues to glow. This glowing reduces the need for refresh memory.



Unless certain precautions are taken, differential aging causes the top and bottom portions of an EL screen to become brighter than the center. One reason is that the driving waveforms spread out slightly at the center. The problem is avoided by using symmetrical waveforms and by reversing the polarity of the pixel rows.

One current disadvantage of plasma displays is their lack of different color outputs. Most displays on the market use a neon gas and have an orange-red color. Neon is used because the driving voltage it needs is lower than that of other gases. Other gases would change the color but demand a higher drive voltage, which increases cost. Another problem with using high-voltage gases (for example, xenon) is their relatively short lifetime.

Electrochromic displays: Another technology that yields low-power, low-cost displays consists of solids or liquids that change color when put into electric fields. These devices are called electrochromic displays. Like LCDs, these displays merely reflect light rather than generating any light of their own. Since most devices of practical interest are based on electrochemical reactions, these devices are commonly called electrochemichromic (ECC) displays. Displays exhibit good color contrast even under high ambient light levels and have a wider angle of view than comparable LCDs. Some devices also possess variable persistence features which allow these displays to form characters while using very little power.

However, indications are that ECC displays will remain in the laboratory for some time. Experimental devices often exhibit electrical characteristics that make them difficult to fabricate into complex displays. For example, devices fabricated thus far often have narrow switching-voltage ranges and low turn-on threshold voltages — characteristics which tend to prevent ECC devices from being used as multiplexed displays. Furthermore, experimental devices tend to have slow switching response and high-power consumption when formed in dot-matrix displays.

Most ECC displays are fabricated from thin films sandwiched between a back-panel electrode and a transparent front electrode, similar to LCDs. A number of materials have been evaluated for these displays, including heptyl viologen bromide, lutetium diphthalocyanine film, and iridium oxide.

In particular, iridium oxide ECC displays may be the closest to commercial use. Researchers are developing ECC displays based on iridium oxide as alternatives to LCDs. The metallic iridium oxide film in these displays turns blue-black when energized. Unlike LCDs, which revert back to their original color once power is removed, the iridium devices retain color until an electrical pulse of the opposite polarity is applied. Under laboratory tests, the iridium displays reportedly have retained color as long as 5 h after being energized and have operated after more than a million on/off cycles.

Raster displays: Raster systems consist of the cathode-ray tube, the display generation circuits, and a graphics processor, which is a separate computer dedicated to handling the video display.

Television screens and RGB monitors are raster displays, meaning they generate images by scanning an electron beam across the CRT in a raster pattern. It is often said that television displays 525 raster lines. This is true, but some confuse display resolution with the number of raster lines TVs can handle. The term display resolution refers to how finely a monitor can produce an image. Some people assume a TV using 525 raster lines will provide a 525-line resolution.

COMPARING DISPLAYS

There are basically four different types of flat-panel displays. These are LCD, gas plasma, vacuum fluorescent, and EL.

High information content LCDs come in several varieties. The simplest is the twisted nematic type, found in watches and calculators. It is inexpensive and typically consumes less than one watt but has low contrast (about 2 or 3:1 in a 500-lux ambient) and slow response. Nematic displays also have a narrow viewing cone. The viewing cone and contrast (5:1) are better in supertwisted nematic displays. However, their response time is even slower and supertwist displays do not have gray-scale capability.

Backlit LCDs offer superior contrast (2.5:1) to those that rely on reflected light. Backlit LCDs transmit light from another source, typically a thick-film EL and, thus, can be considered light valves. They typically yield 5 fL per pixel and have an 80% fill factor, with a 4 fL average brightness for the overall display.

Active-matrix LCDs contain transistor switches for each pixel. This results in good contrast and a wide viewing cone. The transistors allow a stronger field to be impressed across each pixel. This twists the crystal more, improving contrast and viewing angle. However, production problems have prevented the devices from being widely used.

Plasma displays are available in both ac and dc versions. At present, plasma devices are the most inefficient of all displays. And because the light output for either type is proportional to input power, plasma displays consume appreciable power. However, their viewing angle is usually better than an LCD.

Dc-plasma displays contain a gas sandwiched between two electrodes. In most displays, turned-off pixels are maintained at positive voltage bias, or primed, so that when refreshed they have adequate brightness. As a result, the contrast between on and off states is limited to about 8:1. A pixel from a dc-plasma display usually generates about 25 fL. However, the fill factor is only 20%, so display output is only about 5 fL.

Ac plasma uses a capacitive structure, basically two electrodes with a gas between them. An ac sustaining voltage is applied after a pixel has been switched on. Contrast is better than in dc plasma, but power consumption is greater. Plasma displays have an edge over the alternatives when a large, nonrefreshed panel is needed. Once turned on, a pixel need not be refreshed. However, this is a drawback if new information is constantly being written to the screen because it limits the speed at which the screen can be written.

Vacuum-fluorescent units are widely used in small displays. One company has even demonstrated a small (about 1 in.^{2}) flat-panel display.

Early devices used ceramic substrates for an anode. A transparent electrode on glass formed the front surface, and a grid separated the two. Modern devices are similar, but use less-expensive glass for anodes. But cost, power, and reliability remain problems.

When energized, the cathode emits thermal electrons. The grid and anode voltages accelerate the electrons, which strike the anode phosphor. The electrons make the phosphor glow.

Phosphors are usually ZnO:Zn and emit green light. Viewing angles are up to 150°.

But a typical TV does not display all 525 raster lines. Moreover, a TV's vertical resolution is even less than the number of raster lines it displays. When used as a data monitor with a signal applied at the antenna terminals, TVs can generally provide a vertical resolution of about 250 pixels.

Horizontal resolution describes the number of small segments a monitor uses to display a horizontal line. On TVs used as data displays, the set traces out each horizontal raster line in about 60 μs. TV video bandwidth ultimately determines horizontal resolution because it sets the maximum number of transitions between black and white that the set can produce in each horizontal scan line. Typical color bandwidths range from 3.2 to 3.8 MHz.

Horizontal resolution of any video monitor is found from the horizontal scan time and the monitor's video bandwidth. In TVs, the period of the 3.8-MHz bandwidth is the reciprocal of the frequency, 0.26 μs. Since many TVs used as video monitors have the sides of their screen blanked, they have a horizontal scan time of about 40 μs. Dividing the 40 μs scan time by 0.26 μs yields 153. Each period of a 3.8-MHz signal can yield one white-to-black transition. The white state followed by the black state would define two picture elements. The 153 is doubled to yield 306 pixels. Thus, horizontal resolution in a typical TV receiver is, at best, about 306 pixels, and generally ranges from 250 to 300 pixels.

As in vertical resolution, a variety of factors can affect horizontal resolution. For example, picture tube adjustments at manufacture, the high-voltage level at which the tube operates, and focusing all can degrade horizontal response.

RGB monitors have resolutions typically ranging from 512 × 512 pixels (called medium resolution) to 1,280 × 1,024 pixels (high resolution, or high-res). The principal difference between monitors having medium or high-res is in the electronics that deflect the electron beam on the tube to create the image. These circuits include the video and vertical-deflection amplifiers. High-res monitors may also incorporate special circuits that dynamically focus (converge) the color electron guns to maintain high resolution.

The so-called pitch of the CRT shadow mask also affects resolution. A shadow mask is a metal plate that lies just behind the face of a color tube. This metal plate contains many holes through which electron beams hit color phosphors on the face of the screen. The spacing between these holes is referred to as pitch. In TV tubes, which typically use a so-called slot mask, the pitch is about 0.65 mm. But tubes designed to provide higher resolution have smaller pitch, 0.43 mm for medium-resolution tubes and typically 0.31 mm for those with high resolution (some recently developed tubes have 0.21-mm spacing.)

Video tubes with high resolution have more phosphor dots than tubes with lower resolution. This fact explains the trade-off in brightness between high and low-resolution tubes. The image on a TV is brighter than on more expensive high-res monitors. The reason is that the TV phosphor dots are wider and glow more brightly than the smaller phosphor dots on a high-res monitor. Experts say that TVs are up to 60% brighter than monitors of equal size.

Touch screens: Touch screens are showing up in a variety of industrial applications that range from machinery control to monitoring and adjusting continuous processes. The main benefit is that they provide a simpler and less error-prone operator panel. When machine controls are simply spots on a video screen, it is easy to construct an operator interface that most people find simple to learn. This is true even for extremely complicated procedures.

For example, touch panels can simplify operator controls by limiting the number of control options that are displayed at one time. The screen can also be programmed to simultaneously display both controls and helpful comments to guide operators through complicated sequences. Because the screen displays only valid control selections, users have less need to memorize keystroke sequences. This reduces errors and confusion, with the result often being increased operator productivity.

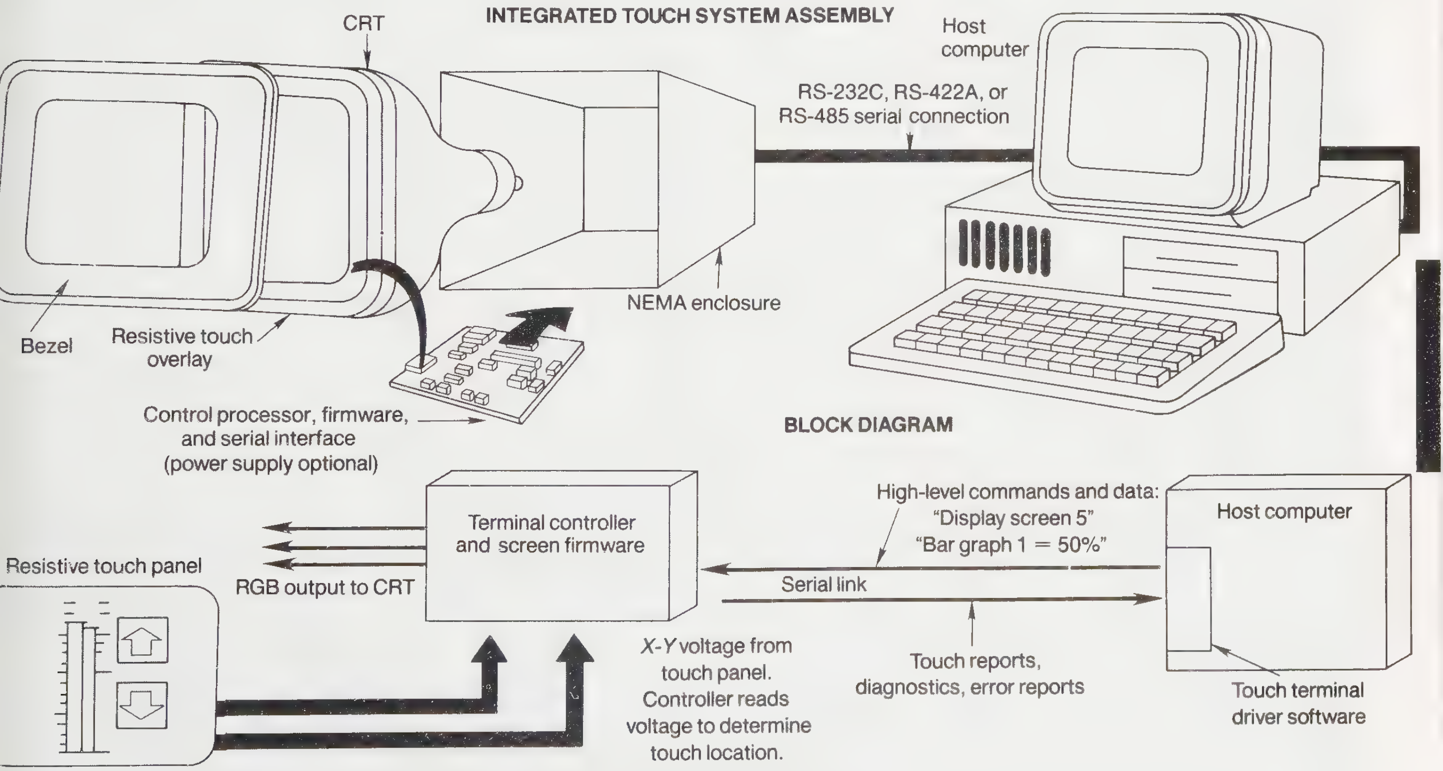
There are economic benefits to touch technology as well. Using a video display as a control panel allows developers to custom design different operator controls for different machines. Often, these controls can use the same type of video display with only software changes required.

Until recently, touch screens usually took the form of an overlay designed to fit over a standard video display screen, which was sold as a separate unit.

One problem developers have had with this approach concerns calibrating the touch-sensitive areas on the overlay with the locations of patterns on the screen. This is basically a software task that, although straightforward, can be time consuming.

Other problems have cropped up when touch displays must be used in applications governed by industry-standard safety regulations. Sometimes, for example, systems must undergo certification by Underwriters' Laboratories or other organizations. Installing an overlay on a UL-certified video terminal may void the certification. The assembly must then go through a potentially lengthy requalification process.

To overcome such problems, fully integrated touch-control screens have recently been developed. These systems combine a video terminal with a touch screen, control electronics, and screen-building software. The assembly is designed as a drop-in subsystem that is simple to build into machine-control systems. More important, some touch-


INTEGRATED TOUCH SYSTEM ASSEMBLY
CRT
Host computer
RS-232C, RS-422A, or RS-485 serial connection
NEMA enclosure
Bezel
Resistive touch overlay
Control processor, firmware, and serial interface (power supply optional)
BLOCK DIAGRAM
Terminal controller and screen firmware
RGB output to CRT
Resistive touch panel
High-level commands and data: "Display screen 5" "Bar graph 1 = 50%"
Serial link
Host computer
Touch reports, diagnostics, error reports
X-Y voltage from touch panel. Controller reads voltage to determine touch location.
Touch terminal driver software

Touch-control subsystem for industrial use consists of a NEMA enclosure, controller, CRT, touch pad, and sealed bezel. The interface to a host is generally through a serial link. Software for these systems generally includes a driver program for the touch panel that resides in the host, as well as screen-building development tools that can download complete screen routines to firmware on the touch-controller board. This firmware reduces the number of commands that the host must send to the terminal to generate a screen.

control subsystems of this nature also have UL certification.

Integrated touch systems are available in a variety of formats. For example, some models are built around RGB color monitors that are compatible with PC graphics cards. Others use NTSC monitors compatible with composite video produced by video discs and tape.

Also available are industrially hardened touch terminals for use on the factory floor. These generally resist temperature extremes, shock and vibration, and have enclosures and seals that conform to NEMA-12, the general industrial standard for splash and dust resistance.

Three types of sensing technologies can be found in the majority of touch screens today: infrared, capacitive, and resistive. Each has benefits and weak points that make it better in some applications than in others.

Infrared touch screens generally employ LEDs and light sensors placed around the periphery of the screen. The LEDs emit a grid of infrared light. When an object interrupts these beams, light sensors register a touch.

A benefit of infrared touch screens is that the LEDs and sensors can often be sealed in the terminal to meet NEMA-4 requirements so that the entire assembly can be cleaned with a hose. But operational drawbacks may make other technologies a better choice for industrial applications. For example, anything that interrupts an LED is interpreted as a touch. This makes infrared systems prone to false actuations from factors such as shirt sleeves, shavings spinning off a part being machined, or even smoke.

Other less-serious drawbacks include parallax, where the operator points to one target but triggers another. This may occur because the infrared grid is physically separated from the screen image by as much as 1.5 in. It is usually a problem only near the screen edges, however, where the CRT curves most severely. Ruggedness may also be an issue, since the unit malfunctions if the LEDs are misaligned.

Capacitive touch technology, in contrast, generally uses discrete touch pads fused directly onto the surface of the glass faceplate. Oscillators are also employed. Touching the pads with a finger or other conductive probe changes the capacitance of the oscillator. This modifies either the oscillating frequency or the waveform shape, which can, in turn, be an indication of a touch.

One problem with capacitive systems is that they are insensitive to nonconductive objects. That means that a user cannot wear gloves when operating the screen. In addition, the sensitivity of these touch systems may be affected by moisture and by the varying natural body capacitance of different operators.

Resistive touch systems employ a membrane stretched over a glass or plastic substrate. Extremely small plastic insulators create a gap between the two layers. Touching a pad on the face of the CRT produces a voltage drop that sensing electronics read as an indication of a touch.

Resistive touch sensors are often preferred on industrial systems because they do not have the drawbacks of the other two methods. The only real problem with resistive screens is that the touch membrane eventually wears out. However, this is not an issue for the majority of actual industrial uses.

Interfacing touch subsystems typically involves connecting to a host computer and generating software to produce application screens. When an operator touches the display to make a selection, a touch report goes to a host computer. This report is generally a numerical value indicating the location of the touch. The host then translates this value into a corresponding command.

Most touch-control units provide signals following ANSI x3.64-1979, the same format used for DEC VT-100 and other widely used terminals. This ANSI standard establishes escape sequences for standard control functions such as setting character attributes, moving the cursor, and clearing the display.

Connections between industrial touch terminals and host computers are generally through serial ports. RS-232C is the usual choice, though RS-422A is needed when the terminal is more than 50 ft away from the host, or if electrical noise may be a problem.

The RS-232C standard specifies the use of a single receive wire, so signals are sensed as voltages between receive and ground. This makes RS-232C signals susceptible to distortion from noise over long distances. On the other hand, RS-422A signals are sent on balanced lines, between positive and negative supply voltages. This ensures signal integrity over distances of up to 1,500 m.

Some touch subsystems have multidrop capabilities, which allow several touch terminals to connect with a common host through a single serial port. Terminals must be equipped with an RS-485 interface to provide such features. The RS-485 standard uses a balanced voltage scheme identical to RS-422A.

Another trend in touch terminals is the increasing availability of software development tools optimized for building application screens. Such tools may be bundled with the subsystem or offered separately. They make it easier to devise screen layouts and usually run on PCs.

Screen-building development tools generally eliminate the need to write a program containing screen manipulation commands. In one such tool, the programmer simply fills in blanks to generate an application screen. The construction of application screens basically involves defining the size, location, and number of touch targets. The developer also decides on the text accompanying each target display. Once screens are complete, they can often be downloaded into nonvolatile terminal memory for use.

Software development aids may also simplify the programming needed to generate the charts and graphs that often accompany touch screens controlling real-time processes. One development aid, for example, simplifies the generation of bar charts by defining size and direction at a single host command. It automatically updates that information each time the host sends the percentage value of full scale for the bar chart.

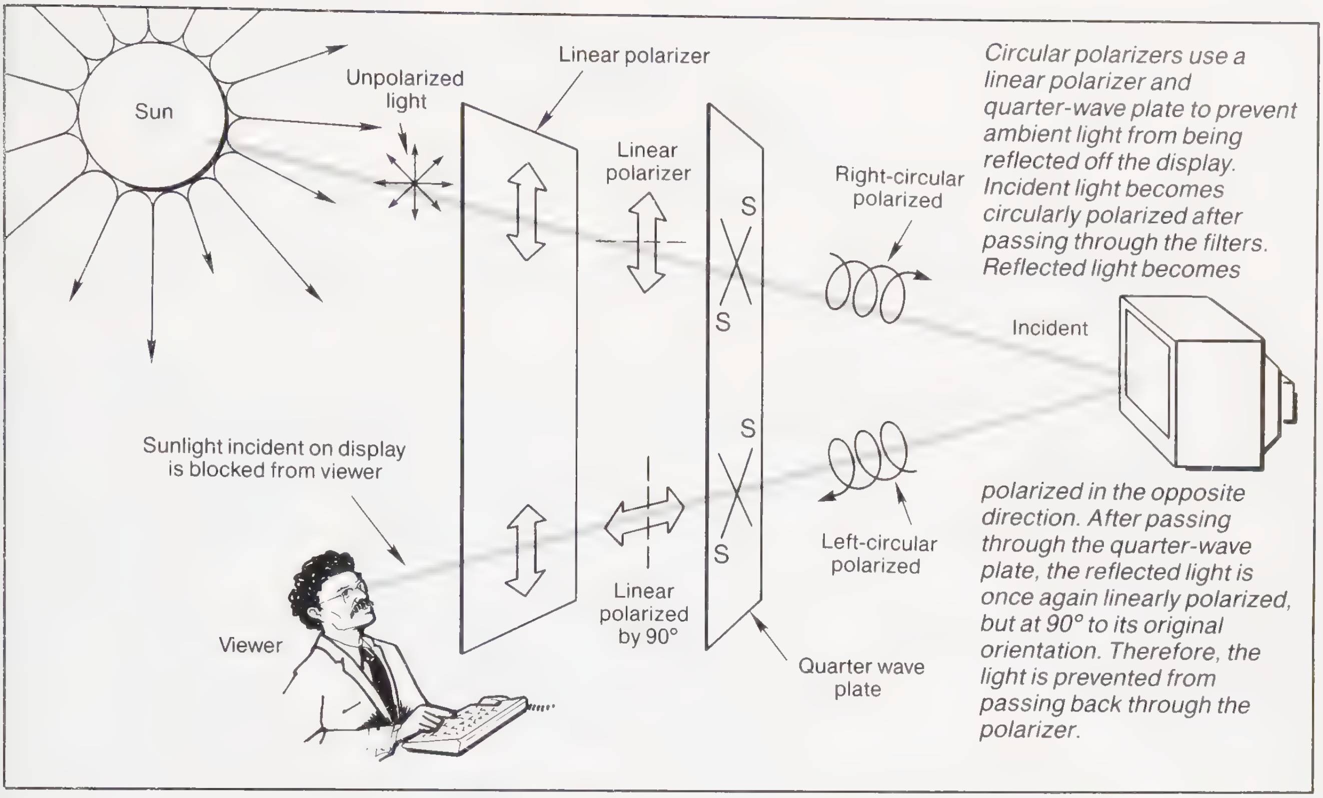
Software-configurable character sets are another enhancement to look for in development aids. This feature is useful in quickly generating a custom display such as a company logo.

Light filters

Many displays are difficult to read when viewed in sunlight. Fortunately, optical filters offer a low-cost solution to this problems.

To specify the proper filter, the lighting conditions a display will be used in and how the eye responds to these conditions must be known. While different types of displays (for instance, CRTs and LEDs) generally have vastly different design considerations, there are common points. In general, a filter should maximize the contrast between display and background. In high ambient light, both display brightness and color are important.

Color is important because the eye is more sensitive to some colors than others. Therefore, even though two light sources may have the same radiant flux, one may appear brighter than another. Eye sensitivity peaks at a wavelength of about 555 nm, which is a yellow-green color. As a result, it is



Circular polarizers use a linear polarizer and quarter-wave plate to prevent ambient light from being reflected off the display. Incident light becomes circularly polarized after passing through the filters. Reflected light becomes polarized in the opposite direction. After passing through the quarter-wave plate, the reflected light is once again linearly polarized, but at 90° to its original orientation. Therefore, the light is prevented from passing back through the polarizer.

difficult to produce high contrast for green displays through filtering.

Color contrast is usually described by two quantities: chromatic distance and chrominance index. These characteristics are determined with a chromaticity diagram. Data points for both the background color and the color of the emitted light are plotted on the diagram. The theoretical chromatic distance between the points is then calculated with an equation that takes the mixing of emitted and reflected light into account.

The smallest discernible color difference is a dimensionless number called threshold chrominance, which has a value of about 0.00384. However, to easily differentiate between two colors, a difference of about 0.027 is recommended. This value is called the unitary color difference.

Chrominance index (IDC) is the ratio of the display's chrominance difference to the unitary color difference. Knowledge of a display's IDC is important for two reasons. First, an IDC of one implies that the display's color difference is just large enough to be easily recognized. Secondly, the IDC, in combination with a similar index for brightness, is a measure of visibility in high ambient-light conditions.

Reflected light: Reflected light usually has both diffuse and specular components. Diffuse reflections are scattered light that appears equally bright regardless of viewing angle. The uniform intensity results from a nearly Lambertian radiation pattern. For specular reflections, light is reflected at an angle equal to its angle of incidence.

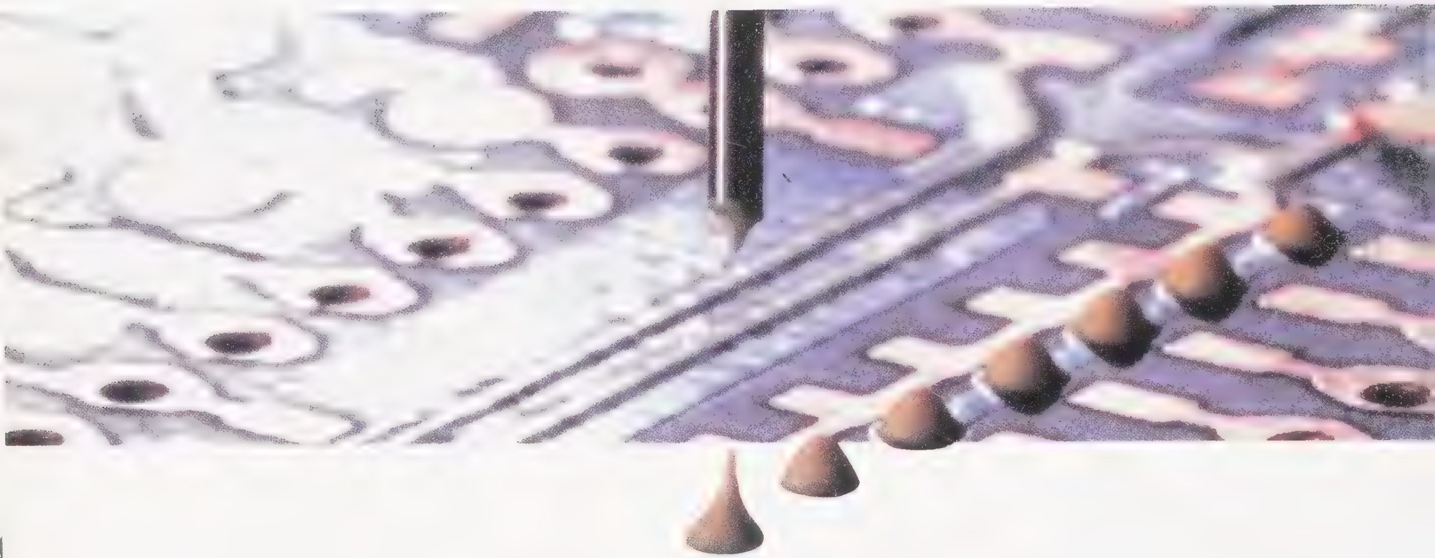
The effect of reflected light is important for two reasons. First, if reflectance is not taken into account, artificially high display contrast ratios may be calculated. In addition, reflections decrease the actual chromatic distance between the background and illuminated elements. One way to diminish specular reflections is with a polarizing filter.

A widely used filter is a circular polarizer which consists of a linear polarizer and a quarter-wave plate. The filter is oriented so that sunlight first strikes the polarizer and then passes through the quarter-wave plate. The quarter-wave plate circularly polarizes the light in one direction. When the light reflects off the display, its direction of polarization is reversed; that is, right-circularly polarized light becomes left-circularly polarized light. Then, when the light passes through the quarter-wave plate, it again becomes linearly polarized, but at 90° to the linear polarizer. As a result, the polarizer absorbs the light. ■

RASTER TUBES

RGB monitors may differ from TVs in the horizontal scan time, the number of raster lines displayed, and shadow-mask pitch to provide high resolution. The shadow mask is a metal plate sitting just behind the CRT screen. Holes in the mask direct electron beams to the proper screen phosphors, one to red phosphors, another to green, and so forth. Shadow-mask holes in RGB monitors are more closely spaced than in TVs, allowing better control for the electron beams. These tricolor phosphors explain why monochrome TVs provide better resolution than color sets. The face of a monochrome tube is solid phosphor, whereas the color tube face is composed of red, green, and blue phosphors. Thus, no matter how close together the color phosphors are placed, they cannot resolve as small a point as can a monochrome screen.

The Adhesive Problem Solvers.



With over 2,700 products, we've got one for you.

A case in point:

In 1980, Emerson & Cuming was approached by an automotive manufacturer developing new technology to mount leadless components to circuit boards. They needed a single-component adhesive with high green strength, fast cure at low temperatures and a high shear thinning index to provide exceptional dot height to width ratios. In response, Emerson & Cuming application engineers pioneered a new series of surface mount, heat or UV-cured adhesives, designed to meet the exacting specifications of the electronics industry. We now supply surface mount adhesives (SMA's) to hundreds of customers worldwide.

Emerson & Cuming offers thousands of standard products and the ability to customize for your specific application. We have the adhesive, encapsulant or coating you need to write your own success story.

To get a free selector guide or product sample for evaluation, give us a call.

1-800-832-4929.

Adhesives • Encapsulants • Coatings

EMERSON & CUMING™
a GRACE company

Making today's products better.
Making tomorrow's products possible.

1991, Emerson & Cuming, Inc.

Circle 409

Interconnections

Interconnection systems are as important as the components they support. Interconnections are responsible for system communication, signal shielding, and electrical protection.

Interconnection systems are responsible for transporting all data and power signals in electrical and electronic systems. Poorly designed connections can ruin otherwise well-designed systems. The integrity of the entire system depends on the conductors (wires, cables, and fiber optics), terminals, connectors, sockets, printed-circuit boards, and backplanes.

Wiring

Several types of wire conductors are used to connect electrical systems. Common types include single wires, twisted pairs, coaxial cable, flexible flat cable, and bundled wires. Single or multiconductor cables are feasible when few connections are needed. However, as product complexity increases, direct wiring becomes costly and unwieldy and other interconnection systems become necessary.

Ribbon cables: Flat cables, sometimes called ribbon cables, contain numerous conductors embedded side by side in flexible strips of plastic insulation. These cables can be mass terminated at low cost. Flat cables carry more current and usually weigh less than round cables having conductors of corresponding size. Nevertheless, flat cables are more commonly used to carry digital signals rather than power. In digital applications, cable qualities that affect signal degradation are more important than current ratings. Cable surge impedance, for example, should match that of connected circuits. Also, if cable capacitance is too high, it can cause crosstalk that garbles data. High-speed signals call for flat cables with low transmission loss.

Conductors in flat cable can be round or rectangular. But rectangular-wire cable costs more, so it is generally used only where cables are repeatedly flexed. Rectangular-wire cable often connects electronic modules inside enclosures with components mounted on a hinged door.

The most commonly used flat cables contain round wire on 0.05-in. spacing. Conductor sizes are awg 26 or 28, solid or stranded, or size 30 solid. Standard flat-cable connectors accommodate this range of wire sizes. Some cables also contain flexible woven-metal ground planes or woven-metal shielding. Larger conductors and bigger spacings are specified to carry more current.

Flat cable is available in almost 20 different widths, containing from 9 to 64 conductors. Grooves in the insulation delineate conductors. These grooves allow flat cables to be split into two or more segments where cables terminate at different locations.

The most common insulation is polyvinyl chloride (PVC), rated for operation in temperatures of up to 105°C.

CABLE TIE MATERIAL QUALITIES

Cable ties are fabricated in several different materials, making them compatible with various rugged or chemical environments. Designs vary, ranging from 4-in. long, 18-lb loop tensile strength ties to 40-in. long, 250-lb types. Commonly used materials include four types of 6/6 nylon: general purpose, flame retardant, weather resistant, and heat stabilized. Other materials include type-12 nylon, polypropylene, fluoropolymer (Tefzel and Halar), and stainless steel.

Three factors used to specify ties are environment, strength, and cost. Environmental considerations include mechanical vibration, weather, and chemical exposure. Cable ties often provide mechanical support for heavy cables. In outdoor applications, weathering considerations become important. Cable ties degrade because sunlight attacks plastic materials over a period of time and breaks down molecular chains. The material breakdown is accompanied by a reduction in tensile strength and elongation, increased brittleness, color changes, and loss of surface gloss.

Carbon black, which is present in nylon and polypropylene cable ties, is an effective way to combat the effects of sunlight. The addition of carbon black, or any other ultraviolet light stabilizer, prolongs the life of plastic products used outdoors. But stabilizers do not eliminate the destructive effects of sunlight completely. Two cable tie materials, Tefzel and stainless steel, have superior ultraviolet-light resistance.

Three modes of tie failure are loss of strength, loss of toughness, or a change in appearance. As exposure to ultraviolet light increases, the material becomes brittle and elongation is reduced. It is important to note that brittle failures occur even when the tensile strength shows no change. Although a change in appearance is not normally a critical failure mode for cable ties, plastic does discolor and lose surface gloss as environmental exposure increases.

Many cable ties absorb water when exposed to high relative humidity. As a result, the tensile strength of the material decreases dramatically. For example, nylon 6/6 exposed to 100% relative humidity increases in weight by up to 8.5%, all of which is water. This absorption reduces tensile strength by up to 50% compared to dry strength. On the other hand, polypropylene ties and those made of type-12 nylon, Halar, and Tefzel absorb little water and are hardly affected by humidity.

When exposed to high temperatures for long periods, most cable ties undergo a material loss because of oxidation, and they actually lose weight. The maximum safe temperature depends on the material used as well as environmental conditions. Initially, plastics become more flexible and weaker when exposed to high temperatures. After a period of time, oxidation may cause embrittlement. The tie is then more susceptible to failure from impact and vibration.

Low-temperature exposure also makes most plastics brittle. However, little loss remains when the material is returned to room temperature, and ties usually regain full tensile strength. Special ties for low-temperature applications are available.

PVC-insulated cables generally connect electronic modules inside enclosures.

Some flat cable, however, has polyethylene insulation with a PVC coating. Polyethylene has lower transmission line losses than PVC. The PVC outer layer protects the polyethylene from physical damage and meets flammability requirements. Though more costly than PVC cable and limited to temperatures of 75°C, dual-insulated cables are suitable for connections outside of enclosures.

Flat cables with conductors on 0.05-in. spacing generally are rated at 1 A for either 150 or 300 V. The current rating is limited more by the connectors than by thermal limitations of the cable. However, flat cable rarely carries this much current or voltage. A high voltage drop is one reason. An awg 26 conductor, for example, has a resistance of approximately 40 mΩ/ft at room temperature. Thus, 1 A flowing through a 25 ft length produces a 1-V drop.

Flat cable, on the other hand, has excellent properties for conveying high-speed digital signals. This quality is maintained in service because the separation between cable conductors remains constant.

Surge impedance is more important than current ratings for data transmission. Good impedance match between cable and connector is also important, especially for fast rise-time pulses. Surge impedance for PVC-insulated 0.05-in. cable ranges from 125 Ω for awg size 30 conductors to 93 Ω for size 26. Impedance of polyethylene-insulated cable ranges from 110 Ω for size 30 to about 80 Ω for size 26.

Capacitance is also important. Capacitance of a signal-carrying conductor in PVC varies from 13 pF/ft for awg size 30 conductors to 15.1 for size 26. For polyethylene, the figures are 15.5 and 20 pF/ft.

Flexible flat cables: Flexible circuits play an important role in the integration of electronics into consumer devices by enabling electronics to be placed in spaces too small or contorted for a rigid board. The cables can be purchased in standard quantities, sizes, and spacings in a variety of insulating materials. They can also be specified for custom applications.

Flexible circuits are typically fabricated by photographic or screening processes. Features are printed on long strips of copper foil laminated on plastic film. Unwanted copper is etched away. Holes are then pierced or drilled. A plastic cover is often applied, after which, individual circuits are stamped out of the strip.

Material selection depends on many factors. For example, many flexible circuits are bent, rolled, or folded only once. Requirements for this application are less stringent than for circuits which flex many times. Cost is also a factor. Polyimide, random-fiber aramid, and polyester are common materials.

Polyimide is the most costly but has the highest temperature rating at 250°C. Polyimide film is available in 0.5 to 5-mil thicknesses but 1 and 2-mil films are most common. Polyimide has excellent dielectric characteristics, chemical resistance, and flexibility. But it is fairly hydroscopic. Consequently, polyimide flexible circuits generally require a drying operation just prior to being soldered into place. Otherwise, absorbed water, when heated, can cause blistering and delamination.

Initial tear strength of polyimide is high. But tears in the material, once started, propagate easily. This propagation, however, can be offset somewhat by suitable design techniques.

Random-fiber aramid has a consistency more like heavy paper than plastic film. It is more hydroscopic and temperature sensitive than polyimide. But random-fiber aramid costs about 85% less and its tear strength is higher. Random-fiber aramids used for flexible circuits are typically 2, 3, or 5 mil thick.

Polyester is the least expensive of the three, about one-third that of random-fiber aramid. It has good chemical, mechanical, and electrical characteristics, and moisture absorption is much lower than that of polyimide or random-fiber aramid. However, its maximum temperature is only 95°C. Flexible circuits made with polyester often distort and delaminate during soldering unless extreme care is used. Consequently, polyester circuits are rarely wave soldered and are typically used with insulation-piercing connectors. Film is available in thicknesses to 14 mil.

Copper foil is the most common flexible-circuit conductor. It is produced in several ways. It can be formed in a rolling process or by an electrodeposition process. Rolled copper foil has a grain structure running parallel to its surface. This grain structure is preferred for circuits that are repetitively flexed.

Gold-plated conductors are used for some applications. In most cases, conductors are plated with nickel prior to gold plating to prevent copper migration into the gold. But nickel is brittle and cracks when flexed repetitively. Copper migration, however, is not a problem where gold plating is at least 30 μin. thick.

Fiber optics: Optical fibers provide high electrical isolation, freedom from electrical noise, and reduced cable size and weight. Electrical signals are first converted to light beams, transmitted over fiber-optic cables, and then reconverted to electrical signals at the termination point.

Optical cables carry much more information than metal wires. The signals are also immune to electromagnetic interference and do not affect other signals outside the cable.

A misalignment of even one μm in a connector, however, may cause the loss of half the power (3 dB). But recently developed connectors keep light losses as low as 0.2 dB. Losses from cable splices also can be minimized by special compliant fixtures used under field conditions.

Optical fibers are made from either glass or plastic. Glass fibers have the lowest losses and the widest bandwidths, but are also the most expensive. Plastic fibers have losses on the order of 100 to 200 dB, and bandwidths of tens of megahertz. Optical communication cables consist of fiber bundles or single fibers to carry information. The trend, however, is toward single fibers.

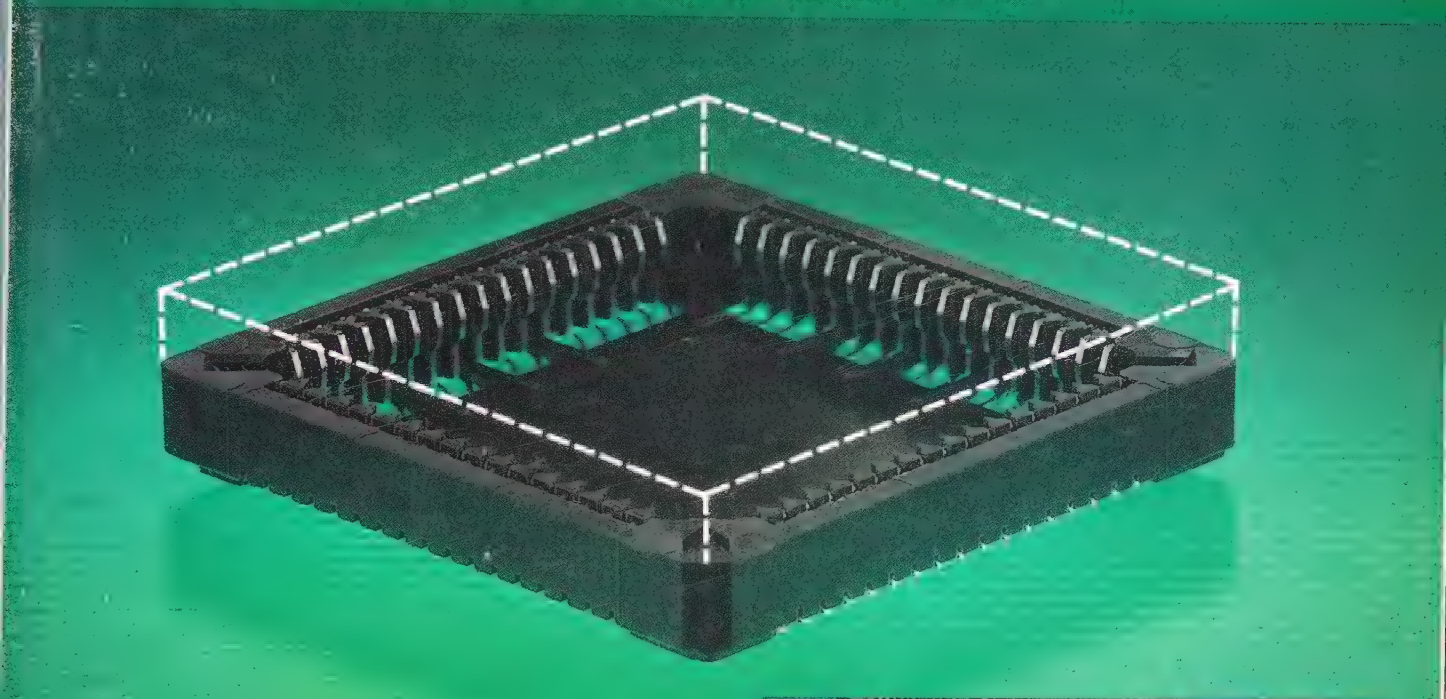
CHOOSING TRANSMISSION CABLE

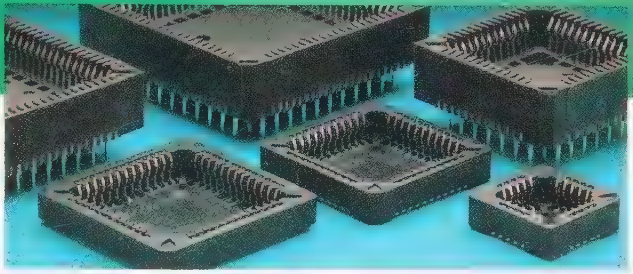
Signals transmitted over long distances are susceptible to noise pickup and capacitive coupling within the cable. In these applications, designers need to select the best type of transmission media. Two types of cable are used most often: twisted-pair and shielded.

Twisted-pair cables equally distribute capacitance along the length of the conductor, keeping capacitance to ground balanced. This reduces capacitive coupling and maintains a high common-mode rejection ratio. With balanced capacitance, noise is induced equally into both wires and is cancelled at the amplifier input.

On the other hand, shielded cable consists of two signal wires surrounded by a conductive shield. The shield connects to common ground or a guard connection on the data-acquisition equipment. Shielding reduces noise along the input lines by as much as 60 dB or more and reduces capacitive coupling in the cable. In addition, shields also absorb magnetic fields and reflect external electric fields. Shielding may be applied to twisted-pair cabling as well.

PLCC sockets. Now half off.





THIS IS AMP TODAY.

Save big where it counts most: real estate and stack height. Our PLCC sockets address your two major concerns—the tight space requirements of today's compact designs, and the need for positive chip retention.

The newest low-profile surface-mount versions, in all popular sizes, take space savings to the max—with half the clearance of our standard types. Now you can get the advantages of socketing in barely more room than the chip itself, and hold on to the low profile you need for tight board stacking and efficient thermal management. Surface-mount styles match PLCC footprints, too, so there's no board redesign.

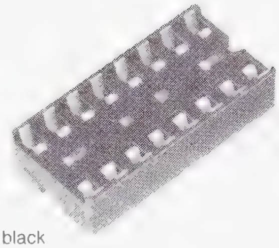
And all our PLCC sockets get solidly into contact, and stay in contact. Their proprietary, controlled-angle interface establishes very high normal forces to ensure positive retention. Short-signal-path contacts float in the housing to accommodate expansion.

Get the help you need: interconnections for your most advanced designs. And get all the advantages of better design where your PLCC meets the board. Call our Product Information Center, 1-800-522-6752 (fax 717-986-7575), for literature. In Canada call 416-475-6222. AMP Incorporated, Harrisburg, PA 17105-3608.

AMP

DIP Sockets

DIPLOMATE Dual Leaf (DL) Contact Sockets - Economy (Open Frame)



Socket accepts .008-.014 [0.2-0.36] thick IC leads

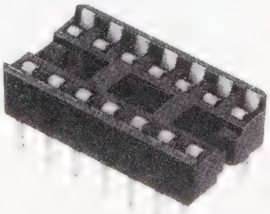
Material and Finish:

Housing—Glass-filled thermoplastic, black
Contacts—Phosphor bronze, tinned

Number of Positions	Part Numbers[1] Straight Leg	Part Numbers[1] Retention Leg
6*	2-641296-5	2-641259-5
8*	2-640463-5	2-641260-5
14	2-641599-5	2-641609-5
16	2-641600-5	2-641610-5
18	2-641601-5	2-641611-5
20	2-641602-5	2-641612-5
22	2-641603-5	2-641613-5
24	2-641604-5	2-641614-5
28	2-641605-5	2-641615-5
40	2-641606-5	2-641616-5
48	2-643574-5	2-643576-5
64**	643575-5	643577-5

[1] All parts, except 64 position, are packaged in plastic tubes ONLY sockets with straight solder tails are recommended for automatic insertion
*Solid body (closed frame)
**Not side-to-side or end-to-end stackable

DIPLOMATE Dual Leaf (DL) Contact Sockets - Standard (Open Frame)



Socket accepts .008-.014 [0.2-0.36] thick IC leads

Material and Finish:

Housing—Glass-filled thermoplastic, 94V-0 rated, black

Number of Positions	Part Numbers — Sockets with Straight Solder Tails[1] — Beryllium Copper Tinned[2]	Part Numbers — Sockets with Straight Solder Tails[1] — Phosphor Bronze Tinned[2]
14	2-641599-1	2-641599-3
16	2-641600-1	2-641600-3
18	2-641601-1	2-641601-3
20	2-641602-1	2-641602-3
22	—	2-644105-3
24	2-641932-1	2-641932-3
24[3]	2-382471-1	2-382471-3
24[4]	2-641604-1	2-641604-3
28	2-641605-1	2-641605-3
40	2-641606-1	2-641606-3
48	2-643574-1	2-643574-3
64	643575-1	643575-3

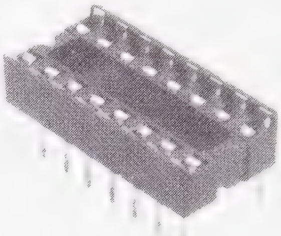
[1] Sockets with retention feature are also available
[2] Sockets with gold plate are also available
[3] .400 [10.16] centerline
[4] .600 [15.24] centerline

DIPLOMATE Over-the-Component (OTC) Socket

Receptacle accepts .008-.014 [0.2-0.36] thick IC leads

Material and Finish:

Housing—Glass-filled thermoplastic 94V-0 rated, black



No. of Pos.	Part Numbers — Sockets with Straight Solder Tails[1] — Beryllium Copper Tinned	Part Numbers — Sockets with Straight Solder Tails[1] — Phosphor Bronze Tinned
16	2-644100-1	2-644100-3
18	2-382060-1	2-382060-3
20	2-382515-1	2-382515-3
28	2-382415-1	2-382415-3
32	2-644018-1[2]	2-644018-3
32*	—	2-644018-5
40	2-382153-1	2-382153-3

[1] Sockets with retention feature are also available
[2] Sockets with gold plate are also available in this size
*Economy version

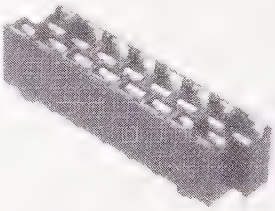
ZIP Sockets

DIPLOMATE Zig-Zag Package (ZP) Sockets

Receptacle accepts .008-.015 [0.2-0.38] thick x .030 [0.76] max. wide rectangular leads

Material and Finish:

Housing—Glass-filled thermoplastic
Contacts—Phosphor bronze, tin-plated



No. of Pos.	Part Numbers
16	2-382006-3
20	2-382007-3
24	2-382008-3
28	2-382009-3
40	3-382040-3

SIP Sockets

DIPLOMATE Dual Leaf (DL) SIP Contact Sockets

Socket accepts .008-.015 [0.2-0.38] thick x .030 [0.76] max. wide rectangular leads

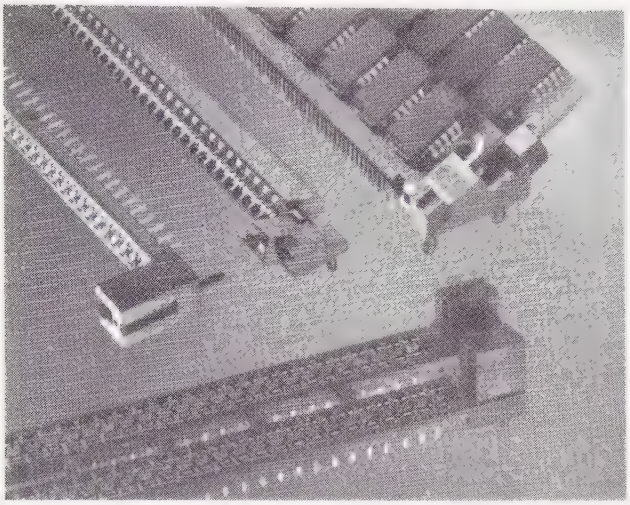
Material and Finish:

Housing—Glass-filled thermoplastic, 94V-0 rated, black
Contacts—Phosphor bronze, tin plated

No. of Pos.	Part Numbers
8	643640-3
9	643641-3
10	643642-3
11	643643-3
12	643644-3
13	643645-3
14	643646-3
15	643647-3
16	643648-3
17	643649-3
18	643650-3
19	643651-3
20	643652-3
21	643653-3
22	643654-3
23	643655-3
24	643656-3
25	643657-3
26	643658-3
27	643659-3
28	643660-3
29	643661-3
30	643662-3

SIMM Sockets

For more information request Catalog 82172



DIPLOMATE SIMM Standard Vertical Sockets

Material and Finish:

Housing—Liquid crystal polymer (LCP), glass filled, 94V-0 rated

Contact—Beryllium copper, bright tin-lead plating

Number of Positions[1]	Single Row	Double Row .300 [7.62] Centerline
22	643922-1	—
30	643930-1	2-382230-1[2]
35	643935-1	—
42	643942-1	—

[1] Other sizes and variations can be made available upon request
[2] Packaged in slide tube for robotic assembly

DIPLOMATE SIMM Low Profile (Angled) Sockets

Material and Finish:

Housing—Liquid Crystal Polymer (LCP), glass-filled, 94V-0 rated

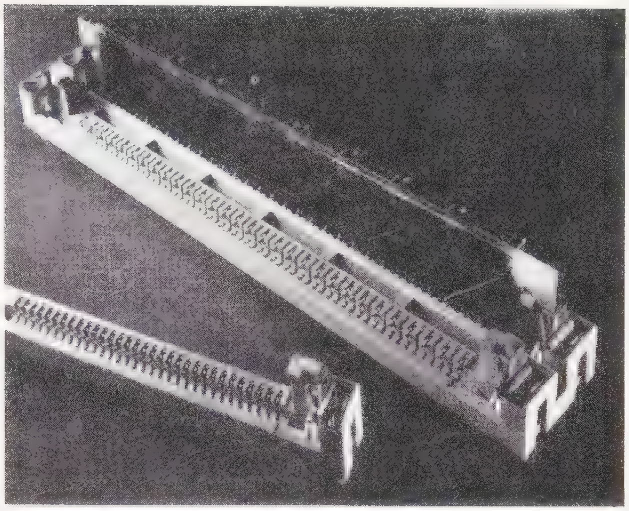
Contact—Beryllium copper, bright tin-lead plating

Number of Positions[1]	Single Row	Double Row
30	2-382030-1	2-382130-1
35	382035-1	—
42	382042-1	—

[1] Other sizes and variations can be made available upon request

Memory Module Extraction Tool

Part No. 382264-1



MICRO-EDGE SIMM Connectors with Metal Latches, .050 [1.27] Centerline

Material and Finish:

Housing—Liquid crystal polymer, 94V-0 rated

Contact—Phosphor bronze with tin-lead plate over nickel plate

Latch—Brass with nickel plate

Vertical Single Row Connectors with Center Post

Standard Polarization

Number of Positions	Part Numbers
	Tin Plate
40	822021-1
64	822021 2
68	822021-3
72	822021-4
80	822021-5

Note: Connectors without center posts and with gold plating are also available

Reverse Polarization

72 Position

Part No. 822030-3

Vertical Dual Row Connectors with Center Post

Number of Positions	Part Numbers
	Tin Plate
64	822090-2
68	822090-3
72	822090-4

Note: Connectors without center posts and with gold plating are also available

MICRO-EDGE SIMM Connectors with Metal Latches, .100 [2.54] Centerline

Material and Finish:

Housing—Liquid crystal polymer, 94V-0 rated

Contact—Phosphor bronze with tin-lead plate over nickel plate

Latch—Brass with nickel plate

Vertical Single Row Connectors

Number of Positions	Part Numbers
	Tin Plate
22	822056-1
30	822056-2
35	822056-3
40	822056-4
42	822056-5

Note: Connectors with gold plating are also available

Vertical Dual Row Connectors

30 Position, .100 [2.54] x .300 [7.62] Centerline

Part No. 822058-2

30 Position, .100 [2.54] x .400 [10.16] Centerline

Part No. 822060-2

Specifications subject to change

AMP

AMP INCORPORATED, HARRISBURG, PA 17105

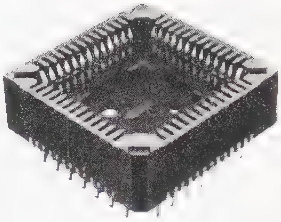
Call 1-800-522-6752 for product information and 1-800-722-1111 for tooling information.

Circle 410

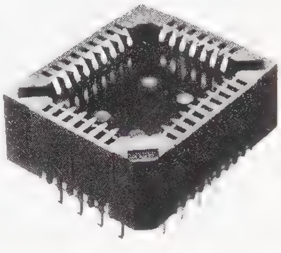
Square and Rectangular Sockets

Square and Rectangular Sockets for PLCC Packages

HPT Sockets with Solder Tails



Square



Rectangular

Materials and Finish:

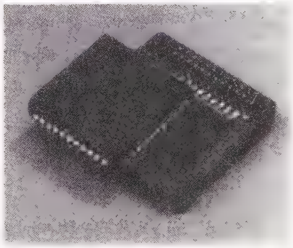
Housing—Polyphenylene sulfide, 40% glass-filled, 94V-0 rated, 220° C

Contacts—Phosphor bronze

Plating—.000150 [0.00381] min. tin-lead (93-7) over .000040 [0.00102] min. nickel

No. of Positions	Package Configuration	Part Number
20	Square	821815-1
28	Square	821581-1
32	Rectangular	821665-1
44	Square	821575-1
52	Square	821551-1
68	Square	821574-1
84	Square	821573-1

Square and Rectangular Sockets for Low Profile PLCC Packages, Surface Mount



Materials and Finish:

Housing—Polyphenylene sulfide, 40% glass-filled, 94V-0 rated, 220° C

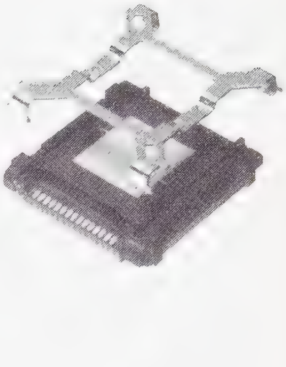
Contacts—Phosphor bronze with .000200 [0.00508] 93/7 tin-lead per MIL-T-10727 Type I over .000050 [0.00127] nickel per QQ-N-290

No. of Positions	Part Numbers	
	Without Locking Posts	With Locking Posts
20	822014-3	822065-4
28	822039-3	822066-4
32*	821977-1	822067-2
44	821979-3	822068-4
52	822041-3	822069-4
68	822029-3	822070-4
84	822151-1	822152-1

*Rectangular

Square Sockets for LCCC Packages

Low Height Chip Carrier Sockets with Solder Tails



Materials and Finish:

Housing—Polyester glass filled

Contacts—Beryllium copper with gold over nickel plating in substrate area and tin-lead over nickel in solder tail area

Cover—Steel with nickel plating

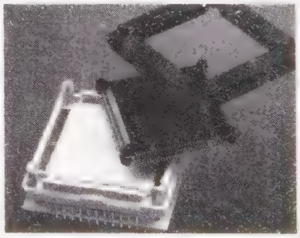
Thruster Clip—Stainless steel

No. of Positions	Assembly with Cover*	
	Leg Length	
	.140 [3.65]	.110 [2.79]
44	55232-1	55232-2
52	55227-1	55227-2
68	55159-1	55159-2
84	55225-1	55225-2
100	55219-1	55219-2

*Cover and assembly available separately

Square Sockets for PQFP Packages

MICRO-PITCH Sockets for Plastic Quad Flat Pack ICs



Materials and Finish:

Housing—High temperature liquid crystal polymer (LCP), 94V-0 rated

Cover—Polyphenylene sulfide (PPS), 94V-0 rated

Contacts—Tin plated phosphor bronze

Insertion/Extraction Tools:
Tool No. 821958-1 (100 Position)
Tool No. 821958-2 (132 Position)
Tool No. 821958-3 (164 Position)

No. of Positions	Part No.	
	Housing Subassembly	Cover
100	821949-4	821939-1
132	821949-5	821942-1
164	822064-6	822111-1

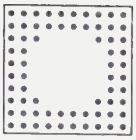
For more information request Catalog 82172

Square Sockets for PGA Packages

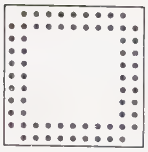
Material and Finish:

Housing—Glass filled polyester, 94V-0 rated

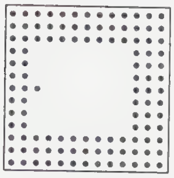
Contacts—Phosphor bronze, plated gold over nickel in the contact area and tin-lead over the solder legs



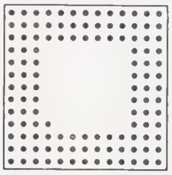
10 x 10
68 Position
(Symmetrical)



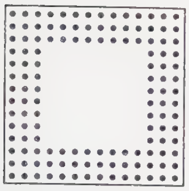
11 x 11
68 Position
(Symmetrical)



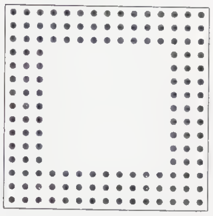
13 x 13
114 Position
Type II
(Non-Symmetrical)



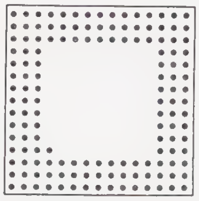
13 x 13
121 Position
(Non-Symmetrical)



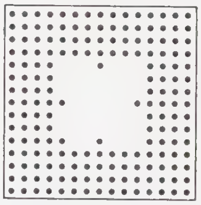
14 x 14
132 Position
(Symmetrical)



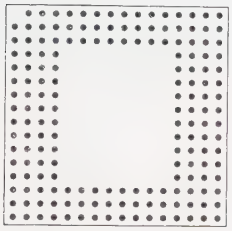
15 x 15
144 Position
(Symmetrical)



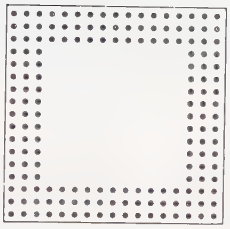
15 x 15
145 Position
(Non-Symmetrical)



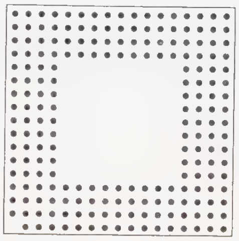
15 x 15
181 Position
(Symmetrical)



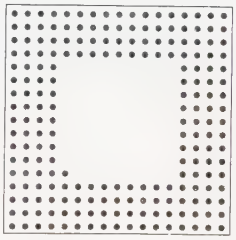
16 x 16
175 Position
(Non-Symmetrical)



17 x 17
168 Position
(Symmetrical)

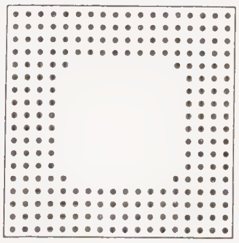


17 x 17
207 Position
(Non-Symmetrical)

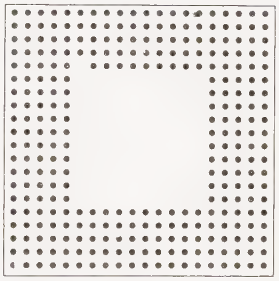


17 x 17
209 Position
(Non-Symmetrical)

Configuration	Part Numbers	
	Closed Frame	Open Frame
10 x 10—68 Pos.	916220-2	—
11 x 11—68 Pos	916221-3	—
13 x 13—114 Pos.	916223-3	—
13 x 13—121 Pos.	916223-2	1-916223-6
14 x 14—132 Pos.	916224-1	916224-8
15 x 15—144 Pos.	916225-1	—
15 x 15—145 Pos.	916225-3	—
15 x 15—181 Pos.	916225-4	—
16 x 16—175 Pos.	—	916226-6
17 x 17—168 Pos.	916227-7	1-926227-2
17 x 17—207 Pos.	916227-6	—
17 x 17—209 Pos.	916227-1	—
18 x 18—179 Pos.	916228-3	—
20 x 20—299 Pos.	916300-3	—



18 x 18
179 Position
(Symmetrical)



20 x 20
299 Positions
(Non-Symmetrical)

AMP

AMP INCORPORATED, HARRISBURG, PA 17105

Specifications subject to change

Call 1-800-522-6752 for product information and 1-800-722-1111 for tooling information.

Circle 410

THIS IS AMP TODAY.

Whether you're looking for .050" center MCA styles, dual-function ISA/EISA types, or .100" or .125" center versions, you can be sure you get the edge connector you need, when you need it.

AMP Standard Edge Connectors come in all the right styles and sizes, with all the engineering advantages you'd expect from the people who established edge connectors as an industry standard. And the immediate availability and in-depth application support you need, from the largest supplier in the world.

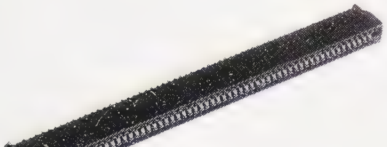
Whatever you're looking for in edge connectors, compare selection, value, and delivery with the industry standard–the AMP Standard Edge lines–and come up a winner. For information on AMP Standard Edge II (.100" and .125"), Standard Edge .050, or Standard Edge EISA connectors, call our Product Information Center at 1-800-522-6752 (fax 717-986-7575). In Canada call 416-475-6222. AMP Incorporated, Harrisburg, PA 17105-3608.

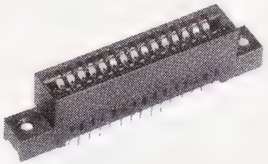
AMP

AMP is a trademark of AMP Incorporated

Circle 696

Standard Edge II Connectors .100 [2.54] and .125 [3.18] Centerline Solder and Wrap Type Posts


Without Mounting Ears


With Mounting Ears

Material:

Housing—94V-0 rated, glass-filled polyester, black
Contact—Phosphor bronze
Finish—.000030 [0.00076] Gold over nickel unless otherwise noted

With Mounting Ears, Wrap-Type Posts

No. of Dual Positions	.100 [2.54] Centerlines .570 [14.48] Post Length	No. of Dual Positions	.125 [3.18] Centerlines .570 [14.48] Post Length
30	4-530396-3	10	4-530825-2
35	4-530396-5	22	4-530825-5
36	4-530396-4	28	4-530825-6
43	4-530396-7	50	5-530825-2
50	4-530396-8		

No. of Dual Positions	Post Length*	.100 [2.54] Centerline Solder Posts			.125 [3.18] Centerline Solder Posts	
		Without Mounting Ears		With Low Mounting Ears[1]	Without Mounting Ears	With Low Mounting Ears[1]
		.000030 [0.00076] Gold Plate	.000015 [0.00038] Gold Plate			
3	.125	7-530843-7	—	—	—	—
	.187	—	—	—	—	—
6	.125	7-530843-5	—	—	530844-1	—
	.187	7-530843-6	—	—	1-530844-2	—
10	.125	5-530843-0	—	—	530844-2	—
	.187	4-530843-9	5-530843-2	—	1-530844-3	—
12	.125	530843-1	2-530843-5	—	—	—
	.187	1-530843-2	—	—	—	—
15	.125	530843-2	2-530843-6	530841-2	—	—
	.187	1-530843-3	—	—	—	—
17	.125	5-530843-3	—	—	—	—
	.187	—	—	—	—	—
18	.125	530843-3	2-530843-7	530841-3	—	—
	.187	1-530843-4	—	—	1-530844-5	—
20	.125	5-530843-4	—	—	—	—
	.187	—	—	—	—	—
22	.125	530843-4	2-530843-8	530841-4	530844-5	—
	.187	1-530843-5	—	—	1-530844-6	—
25	.125	530843-5	2-530843-9	530841-5	—	—
	187	1-530843-6	—	1-530841-6	—	—
28	.125	530843-6	—	530841-6	—	—
	.187	1-530843-7	—	—	1-530844-7	—
30	.125	530843-7	—	530841-7	—	—
	.187	1-530843-8	4-530843-2	1-530841-8	1-530844-8	—
31	.125	6-530843-5	7-530843-0	—	—	—
	.187	6-530843-3	—	—	—	—
35	.125	2-530843-3	—	—	—	—
	.187	2-530843-4	—	—	—	—
36	.125	530843-8	—	530841-8	—	—
	.187	1-530843-9	—	1-530841-9	1-530844-9	1-530842-9
40	.125	530843-9	—	—	—	—
	.187	2-530843-0	—	530841-9	2-530844-0	—
43	.125	1-530843-0	—	—	1-530844-0	—
	.187	2-530843-1	—	2-530841-1	—	—
50	.125	1-530843-1	—	1-530841-1	1-530844-1	1-530842-1
	.187	2-530843-2	—	2-530841-2	2-530844-2	2-530842-2
52	.125	645169-3	—	—	—	—
60	.125	5-530843-5	5-530843-7	5-530841-3	—	—
	.187	5-530843-6	5-530843-8	—	—	—
70	.125	5-530843-9	6-530843-1	—	—	—

*Metric equivalents for post length are .125 [3.18]; .187 [4.75].

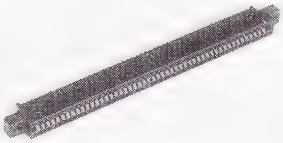
[1] Low mounting ears .360 [9.14].

Specifications subject to change.

Call 1-800-522-6752 for product information and 1-800-722-1111 for tooling information.

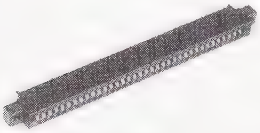
AMP
AMP INCORPORATED, HARRISBURG, PA 17105

Standard Edge II Connectors .100 [2.54] Centerline Card Extenders



Number of Positions	Part Number
30	1-530826-0
36	530826-1
40	530826-2
43	1-530826-2
50	530826-3

Standard Edge II Connectors .125 [3.18] Centerline Card Extenders



Number of Positions	Part Number
18	530384-8
30	530384-1
36	530384-2
50	530384-3

Material:

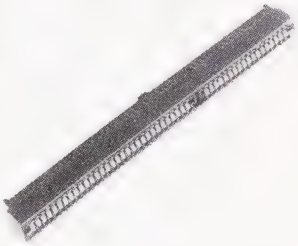
Housing—94V-0 rated, glass-filled polyester, black
Contacts—Phosphor bronze
Finish—Gold over nickel accu-plating in contact area, .000030 [0.00076] thick; tin plated posts.

Mounting Block

Material:

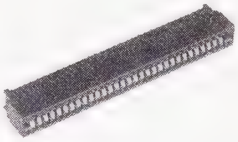
Natural Color Nylon
Kit Part No. 531250-1
Each kit includes 2 mounting blocks, 2 self tapping screws, #5 x .375 [9.52] 2 roll pins, .075 x .25 [1.57 x 6.35]

Standard Edge II Connectors .100 [2.54] Centerline



18/31 Card Slot

52 Dual Position **Part No. 645169-2**
Retention Style I

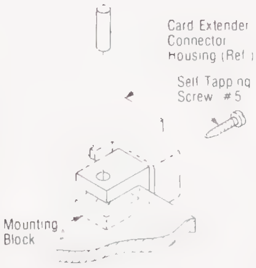


18 Dual Position **Part No. 645235-4**
31 Dual Position **Part No. 645235-1**
Retention Style III
(Other configurations available)

Material:

Housing—Glass-filled polyester, black
Contact—Phosphor bronze
Finish—Gold over nickel accu-plating in contact area, .000030 [0.00076] thick; tin plated posts

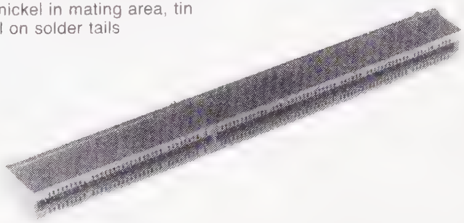
Short Keying Plug Part No. 650025-2



Standard Edge .050 Series Connectors .050 [1.27] Centerline

Material and Finish:

Housing—Polyphenlyene sulfide
Contacts—Phosphor bronze, plated gold over nickel in mating area, tin over nickel on solder tails



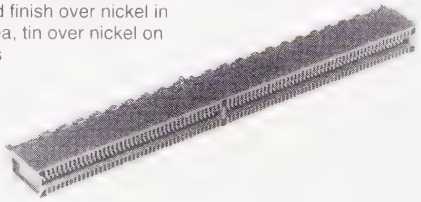
No. of Positions	Post Length*	Part Numbers	Configuration
15	.100	650712-1	End Key
23	.100	650090-7	1 Key-2 Pylons
	.140	650181-3	1 Key-2 Pylons
25	.100	650719-1	End Key
30	.100	650090-6	1 Key-2 Pylons
40	.100	650090-3	1 Key-2 Pylons
	.140	650181-2	1 Key-2 Pylons
45	.100	650090-2	1 Key-2 Pylons
56	.100	650090-1	1 Key-2 Pylons
	.140	650181-1	1 Key-2 Pylons
66	.100	650091-1	1 Key/1 Web-2 Pylons
	.140	650091-2	1 Key/1 Web-2 Pylons
70	.100	650231-5	1 Key/1 Web-2 Pylons
80	.100	650090-9	1 Key-2 Pylons
91	.100	650092-1	1 Key-2 Pylons
	.140	650092-2	1 Key-2 Pylons
97	.100	650706-1	1 Key/1 Web-2 Pylons
	.140	650706-2	1 Key/1 Web-2 Pylons
101	.100	650707-1	1 Key/1 Web-2 Pylons
	.140	650707-2	1 Key/1 Web-2 Pylons
120	.100	650231-2	1 Key/1 Web-2 Pylons
	.140	650231-1	1 Key/1 Web-2 Pylons

*Metric equivalents for post length are .100 [2.54], .140 [3.56]

Standard Edge EISA Connector .050 [1.27] Centerline (.100 [2.54] Staggered Grid)

Material and Finish:

Housing—Vapor phase compatible thermoplastic
Contacts—Beryllium copper, plated gold finish over nickel in mating area, tin over nickel on solder tails



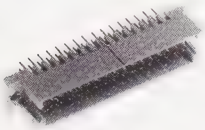
188 Position, Part No. 646039-1 (with Guide Post Retention)
646040-1 (with Solder Tail Retention)

Eurocard Connecters Post Assemblies with Solder Posts

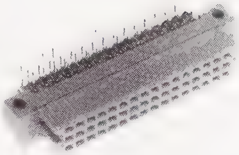
Type ½R Connectors
.100 [2.54] Grid
3 Row, Inverse Style

Material and Finish:

Housing—Thermoplastic, gray
Contacts—Copper alloy, plated to DIN 41612, Class II



Pin Assembly with Solder Posts
48 Position **Part No. 650477-5**
Post length .180 [4.57] Rows loaded A,B,C



Receptacle Assemblies with Solder Posts
48 Position **Part No. 650868-4**
Rows loaded A,B,C

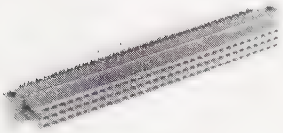
Standard
Type R Connectors
.100 [2.54] Grid
3 Row, Inverse Style

Pin Assembly with Solder Posts

Material and Finish:

Housing—Thermoplastic, gray
Contacts—Copper alloy, plated to DIN 41612, Class II

No. of Contacts	Rows Loaded	Post Length
		.180 [4.57]
96	A, B, C	650470-5
64	A, C	650934-5



Material and Finish:

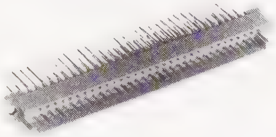
Housing—Thermoplastic, gray
Contacts—Copper alloy, plated to DIN 41612, Class II

Type R
Receptacle Assemblies with Solder Posts

No. of Contacts	Rows Loaded	Post Length	
		.110 [2.79]	.168 [4.27]
96	A, B, C	650461-4	650462-4
64	A, C	650870-4	650871-4

Standard
Type R Connectors
.100 [2.54] Grid
3 Row, Inverse Style

Pin Assemblies with ACTION PIN Posts for .093 [2.36] to .125 [3.18] Thick Printed Circuit Boards

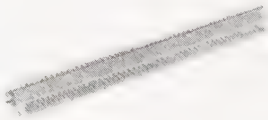


Material and Finish:

Housing—Thermoplastic, gray
Contacts—Copper alloy plated as follows:
A—DIN 41612, Class II in contact area, tin-lead on tail
B—Din 41612, Class II in contact area and last .200 [5.08] of tail

No. of Contacts	Rows Loaded	Contact Plating	Post Length		
			.250 [6.35]	.521 [13.23]	.733 [18.62]
96	A, B, C	A	650889-5	650909-5	531787-1
		B	—	1-650909-4	532525-1
64	A, C	B	—	1-650930-4	—

Expanded
Type R Connectors
.100 [2.54] Grid
3 Row, Inverse Style



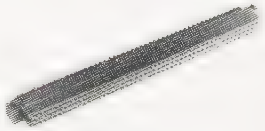
Pin Assemblies with Solder Posts

Material and Finish:

Housing—Thermoplastic, gray
Contacts—Copper alloy, plated to DIN 41612, Class II

No. of Contacts	Rows Loaded	Post Length
		.180 [4.57]
120	A, B, C	650910-5
150	A, B, C	650911-5

Receptacle Assemblies with Solder Posts



Material and Finish:

Housing—Thermoplastic, gray
Contacts—Copper alloy, plated to DIN 41612, Class II

No. of Contacts	Rows Loaded	Post Length	
		.110 [2.79]	.167 [4.24]
120	A, B, C	650874-4	650876-4
150	A, B, C	650875-5	650877-4

Specifications subject to change

Call 1-800-522-6752 for product information and 1-800-722-1111 for tooling information.

AMP AMP INCORPORATED, HARRISBURG, PA 17105

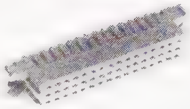
Circle 696

Eurocard Connectors Post Assemblies with Solder Posts

For more information request Catalog 82721

Type ½C Connectors
.100 [2.54] Grid
3 Row, Standard Style

Receptacle Assembly with Solder Posts



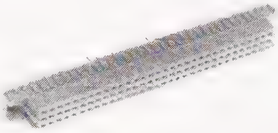
48 Contacts **Part No. 535071-4**
Post Length .180 [4.57]

Standard
Type C Connectors
.100 [2.54] Grid
3 Row, Standard Style

Receptacle Assemblies with Solder Posts

Material and Finish:

Housing—Thermoplastic, gray
Contacts—Copper alloy, plated to DIN 41612, Class II



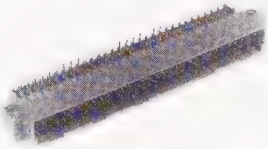
No. of Contacts	Rows Loaded	Post Length		
		.180 [4.57]	.130 [3.3]	.098 [2.49]
96	A, B, C	535043-4	535090-4	535089-4
64	A, C	650408-4	650956-4	650458-4

Standard
Type C Connectors
.100 [2.54] Grid
3 Row, Standard Style

Pin Assemblies with Solder Posts

Material and Finish:

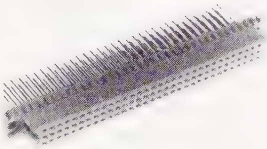
Housing—Thermoplastic, gray
Contacts—Copper alloy, plated to
[1] DIN 41612, Class II
[2] DIN 41612, Class III



No. of Contacts	Part Numbers	
	Post Length	
	.104 [2.46]	.130 [3.30]
96	650473-5[1]	650947-5[1]
96	650473-9[2]	650947-9[2]
64	650945-5[1]	650951-5[1]

Receptacle Assemblies with ACTION PIN Posts

(For .093 [2.36] printed circuit boards)



Material and Finish:

Housing—Thermoplastic, gray
Contacts—Copper alloy, plated to
[1] DIN 41612, Class II in contact area, tin-lead on tail
[2] DIN 41612, Class II in contact area and last .200 [5.08] of tail

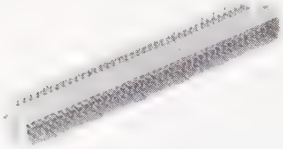
No. of Contacts	Rows Loaded	Post Length		
		.190 [4.83]	.512 [13]*	.669 [17]*
96	A, B, C	—	1-215912-4[2]	1-215614-4
96	A, B, C	535032-4	215912-4[1]	215614-4[1]

*Use Insertion Tool No. 535072-1 for .512 [13] and .669 [17] post lengths

Expanded
Type C Pin Assemblies

Material and Finish:

Housing—Thermoplastic, gray
Contacts—Copper alloy, plated to DIN 41612, Class II

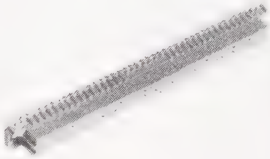


No. of Contacts	Rows Loaded	Post Length	
		.104 [2.64]	.130 [3.30]
120	A, B, C	650906-5	650949-5
150	A, B, C	650907-5	650950-5

Expanded
Type C Receptacle Assemblies

Material and Finish:

Housing—Thermoplastic, gray
Contacts—Copper alloy, plated to DIN 41612, Class II

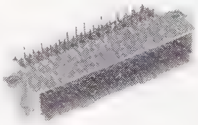


No. of Contacts	Rows Loaded	Post Length		
		.098 [2.49]	.130 [3.30]	.180 [4.57]
120	A, B, C	535097-4	535098-4	535099-4
150	A, B, C	650404-4	650405-4	650406-4

Type ½C Pin Assemblies

Material and Finish:

Housing—Thermoplastic, gray
Contacts—Copper alloy, plated to DIN 41612, Class II



No. of Contacts	Rows Loaded	Post Length	
		.104 [2.64]	.130 [3.30]
32	A, C	650946-5	650952-5
48	A, B, C	650478-5	650948-5

Fiber bundles generally distribute random light for display or illumination.

Optical fibers consist of core and cladding layers, each having a different index of refraction. The layers are constructed to optimize the cable's numerical aperture (NA). A large NA allows light rays to enter the fiber at greater angles off the fiber's center. The NA is determined by core and cladding thickness and indices of refraction.

Light guided by a fiber separates into the "modes" of propagation permitted in that fiber. Smaller diameter fibers allow fewer modes. Fibers are classified by the way light propagates through them: single-mode step, multimode step, and multimode graded index.

A single-mode fiber allows only one mode of light to propagate. The fiber has a very small core with a diameter on the order of one wavelength of the transmitted light. Single-mode propagation allows a large signal bandwidth, which increases the information capacity of the light. But practical difficulties arise in coupling light energy into small fibers.

The multimode step index fiber allows many propagation modes. Coupling light into the fiber is easier because the fiber core can be made larger. But the propagation modes have different velocities in the fiber. These velocities cause what is called dispersion or pulse spreading. The effect is analogous to a high-frequency electrical signal put through a low-pass filter; sharp waveforms become rounded and spread out. Hence, dispersion limits the bandwidth of the signals that can be guided.

In the multimode graded index fiber the refractive index falls off gradually from the core center to the outside of the cladding, with no distinct core-cladding interface. The gradually changing refractive index allows all propagating modes to have nearly the same velocity, resulting in no pulse spreading. Core diameter in graded index cables is relatively large and allows considerable light to enter the fiber.

Terminals

Terminal selection depends on the type of wire used, operating environment, and factors such as current levels and local electrical codes.

Temperature: Crimping wires to terminals sets up the conditions for stress relaxation. This relaxation can be a product of creep or recrystallization. Creep is accompanied by dimensional changes and is caused by slow atomic diffusion of the material to accommodate crimp stresses. The rate of creep increases with temperature and is higher in aluminum than in copper. Aluminum, for example, creeps significantly at room temperature.

Recrystallization, which is not accompanied by dimensional changes, can occur in high-purity copper at 250°F. Stress relaxation caused by creep or recrystallization reduces residual contact pressure to where the terminal fails due to increased contact resistance. At elevated temperatures, wire can creep out of the terminal as well.

Differences in thermal expansion rates of terminal and wire aggravate the stress relaxation problem. For example, when an aluminum-to-copper joint is heated, the aluminum expands at a 40 to 50% greater rate than copper. In some cases, mechanical stresses exceed the elastic limit of the aluminum, causing plastic deformation. Furthermore, when the joint cools, the cross-sectional area of the aluminum may be significantly reduced and could result in joint failure.

Two dissimilar metals or alloys in contact at elevated temperatures can also generate a thermal emf which shows up as a spurious, low-level dc signal. Depending on the operating signal levels and temperatures involved, it may be necessary to use terminal, wire, and other contacting metals of the same material.

Corrosion: The types of corrosion that occur in terminals are atmospheric and galvanic. Atmospheric corrosion depends largely upon the contaminant present in the environment. Most atmospheric corrosion, especially oxidation, increases with temperature.

Galvanic corrosion occurs when two different metals are coupled in the presence of a solution containing ionized salts. The severity of galvanic action depends on several electrochemical properties of the metals as well as the solution involved. The most common occurrence involves saltwater as the electrolyte.

Vacuum: When metals are used in a vacuum at elevated temperatures, high vapor-pressure elements can vaporize from the material. Ordinarily, alloys selected for high-temperature applications do not contain such components. However, alloys such as brass contain zinc and are undesirable in a vacuum if they are load-bearing components at elevated temperatures. Under these conditions, the components vaporize rapidly and deposit in a cooler temperature zone.

Outgassing in a vacuum environment is also severe with some insulating materials. Not only does outgassing contaminate the vacuum, but the physical and electrical characteristics of outgassed material change appreciably.

Radiation: Atomic radiation does not affect electrical performance of crimped terminals. However, the properties of most common plastic insulating materials used on wire and terminals degrade drastically under prolonged exposure and eventually become useless as an electric insulator.

Current: Terminals should be able to carry at least as much current as the wire for which it is rated. Such a terminal has a larger heat-dissipating mass than the wire, and it usually operates at a lower temperature. In this instance, the effects are similar to heating a joint made of two metals having different rates of thermal expansion.

Voltages: High operating voltages require special insulation, spacing, and location of the terminals. Extremely low operating voltages require special consideration as well. An electrical connection that performs satisfactorily at levels above 10 to 15 V may not be suited for signals in the mV range. With the exception of gold, metallic surfaces are usually covered with insulating oxide or sulfide films. In practice, these films are generally rubbed off when the connection is made, or they break down under circuit voltages. However, when these films remain, they can impede current flow at mV-signal levels. Generally, a connection that conducts well at 1 mV will conduct at lower voltages.

Insulation: Preinsulated terminals come in many types and require less handling and only one crimp. They are also slightly more expensive than uninsulated ones.

For moistureproof, high-temperature applications, a special post-insulated terminal is usually required. This type requires two crimps and extra handling and assembly time. Another use for postinsulation is where only a few terminals require insulation. Postinsulation tubing allows the same tooling and the same uninsulated terminal to be used for all connections.

Two types of insulation tubing are available: flexible and shrinkable. In both cases, the tubing is slipped onto the wire before the terminal crimp is made. Another postinsulation technique is the snap-on and premolded plastic type often used to insulate push-on terminals.

Terminal blocks

Terminal blocks require no wire preparation except stripping, and are easily installed with a screwdriver. Terminal blocks accept a wide range of awg wire sizes, provide ready hookup of wires from different components, and assure fast disconnection/reconnection during maintenance and troubleshooting.

Terminal bodies often are made from a copper alloy that has the same expansion coefficient as the wire. This prevents loosening between metals with different thermal expansion rates and provides low contact-resistance values. Corrosion, normally caused by electrolytic action between two different metals, is also eliminated.

There are two basic styles of terminal blocks, European and North American. European terminal blocks are physically smaller than North American blocks having the same voltage and current ratings. And unlike hardware made in North America, all mounting hardware for European terminal blocks follows a standard DIN format. Blocks from one vendor can be installed on rails from another.

Terminal blocks in the North American style generally are vendor specific. Blocks and rail hardware from one manufacturer usually will not work with equipment from others.

Another difference between North American and European blocks is in connection techniques. European wire terminations follow what is called a dead-front configuration. Termination hardware is recessed within the plastic block housing, isolating electrically live parts. Maintenance personnel can touch live blocks with minimal chance of shock hazard or electrocution. North American blocks employ a more open design.

The simplest terminal blocks, called electrical blocks, merely join wires or cables. These devices accept wire sizes ranging from about 12 awg to 500 mcm with a maximum voltage rating of 600 V. The blocks either snap into a metal rail or are screw mounted on the panel of the control enclosure.

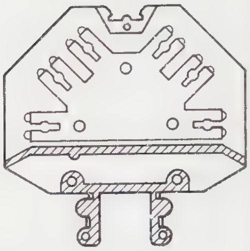
There are three styles of DIN rails: C (also called G or asymmetric), flat (also called symmetric), and mini rail. C and flat rails are used in systems rated to 600 V. Terminal blocks on mini rails handle voltages to 300 V.

Special terminal blocks combine simple terminations with other functions found in the control panel such as fusing and disconnects. Fusible terminal blocks are widely used and generally contain ferrule fuses rated at 3 to 5 A, although some devices contain up to 30-A fuses. Special terminal blocks may also incorporate circuits that perform visual annunciation, surge suppression, and voltage regulation.

Another type of terminal block is of-

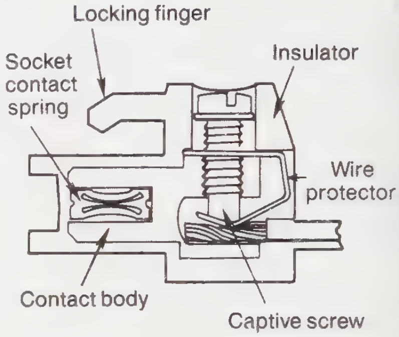
TERMINAL BLOCK CONTACT STYLES

Quick-connect contacts consist of a simple tab or flat blade designed to take a push-on connector installed on the wire end. Such a connector is a force-fit metal sleeve which is pushed over the tab. This type of contact is commonly used for #12 and smaller wires.

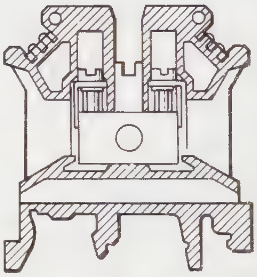


QUICK CONNECT

Two-part plug-in dead-front connectors can provide position interlocking for shock and vibration. Socket-mating springs on quality connectors may provide as many as seven points of contact on posts. Use of beryllium-copper wire protectors makes the connectors applicable to both single and fine-stranded wire termination. Special flush-mount designs are available to minimize the stress on board solder joints that occurs when screw terminals are tightened.

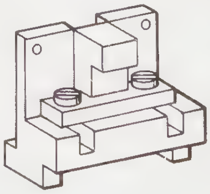


Tubular contacts consist of a length of metal tubing, rectangular in cross section, with a screw threaded through the top and sides of the tube at each end. Where the flat bottom of the screw is used to provide the pressure on the inserted wire, the contact is often called a *tubular screw contact*. Where a flat pressure plate is used under the screw, the contact is called a *tubular clamp contact*. Preferably, the clamp should be held captive to the screw. Clamp contacts are mainly used with fine-stranded wires.



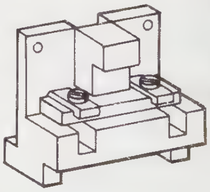
TUBULAR

Strap-screw contacts consist of a screw through each end of the connector strap. A wire is attached to the contact either with a ring or spade lug or by simply looping the wire around the screw and tightening it down.



STRAP-SCREW

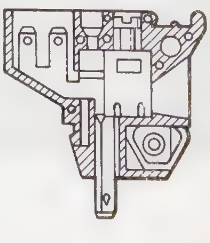
Strap-clamp contacts consist of a screw through each end of a flat strap, with a wire-clamping element under the screw head to exert pressure on the wire. The bare wire is inserted in the pressure contact.



STRAP-CLAMP

Feed-through contacts have studs through the mounting surface. These contacts are used where the wire leads must pass through a wall directly under the block or as close to the side as possible. Wires are connected with strap-screw or stud contacts.

FEED-THROUGH



ten called an electronic block. These devices typically work with smaller wire sizes common to electronic applications, 30 to 14 awg at 300 V or less. The blocks generally mount and solder onto printed-circuit boards. They transmit power or control signals to circuit components through solder pins that are mechanically connected to the clamping body.

Connectors

Connectors are divided into four categories based on operating environments: commercial, industrial, military, and hermetic.

Commercial applications are situations where outside temperatures and atmospheric conditions are the least critical. The connector simply acts as a device for maintaining electrical continuity, allowing a less sophisticated connector to be used.

Industrial connectors are offshoots of commercial models. Industrial connectors perform in more rugged environments. Hazards include thermal shock, corrosion, vibration, physical jarring, and sand and dust.

Military connectors are reliable and have the ability to withstand extreme environmental conditions. They are fabricated to military specifications and are available from a variety of sources.

Hermetically sealed connectors have performance requirements that are as rigid as military types. They are used in chemical-processing systems, industrial and commercial refrigeration units, and in underwater and aerospace electronic applications.

Designers can select from several different connector materials:

Brass has excellent conductivity, but it cannot withstand many insertion and withdrawal cycles. Brass loses flexibility as it ages and under repeated stress is subject to crystallization, which significantly lowers conductivity. Brass is suitable for noncritical, low-contact-force applications. It is easily crimped, soldered, welded, and brazed.

Beryllium copper has excellent mechanical, electrical, and thermal properties and resists corrosion and wear. It is the best electrical conductor of any spring alloy of comparable hardness. Beryllium copper is stronger, more resistant to fatigue, and withstands more insertion and withdrawal cycles than any other copper-base spring alloy. Its cost is the highest of the basic contact materials.

Nickel-silver alloys are oxidation resistant, and do not always require plating. Nickel-silver is susceptible to stress corrosion, although not to the extent of brass.

Filming characteristics of plating metals

Grouping	Characteristics	Examples
Class A	Forms little or no surface fillms and makes pure metal-to-metal contact with lightest contact forces.	Gold and high-percentage gold alloys.
Class B	Grows relatively little film, but is not as noble as gold. May require moderate contact forces to make clean.	Platinum, palladium, iridium, rheniium, and other
Class C	Has film-forming tendencies under certain environmental conditions. May require sliding action and high contact force to assure clean metallic contact.	Rhodium, silver, and high-silver alloys.
Class D	Nonnoble base metal. Forms thick and often strong films, requiring heavy contact forces to make metallic contact. Contact is often quasi-metallic and conduction is through a film or by the tunnel effect.	Copper, nickel, tungsten, copper alloys, aluminum and tin.

Gold is an excellent conductor and a highly stable plating material. It has the lowest contact resistance and provides the best protection from corrosion. Hard gold platings are recommended for frequent insertion/withdrawal cycles. For even greater cycling, gold can be impregnated with graphite with a minimum increase of contact resistance.

Gold-over-silver underplating is good for dry-circuit (millivolt, milliampere range) applications because it provides low contact resistance. Because its corrosion resistance is only moderate, the use of this combination is limited.

Gold-over-nickel is a widely used plating combination because it provides the surface characteristics of gold, while the hard underplating of nickel prevents migration of the base metal and minimizes the amount of gold required.

Silver is a general-purpose plating for power contacts. However, shelf life is poor and silver tarnishes when exposed to the atmosphere, increasing contact resistance. Although this oxide coating is undesirable in low-level circuits, it does not affect contacts carrying higher currents.

Nickel has good corrosion resistance, fair conductivity, and is generally used as an undercoat for high-temperature environments to prevent migration of silver through gold. Nickel has good wear resistance, but it may crack during crimping if not properly plated onto the base metal.

Rhodium is used when exceptional wear characteristics are required. It has a lower conductivity than gold or silver, but on thin platings this increase in resistance is acceptable.

Tin has good conductivity and excellent solderability. It is a low-cost finish with poor wipe resistance best suited for connections requiring very few mating cycles. Tin is not a noble metal and will corrode.

Rhodium-over-nickel provides maximum wear resistance and is suitable for high-temperature operation. However, this combination has higher contact resistance than other platings.

Insulator materials used in connectors are normally plastics. Plastics provide the dielectric and mechanical characteristics required of the connector body. The dielectric selected is governed not only by the application, but also by the configuration and size of the connector body. These considerations include wall thickness, section-thickness variations, and types of inserts needed. The plastic is normally chosen for lowest material cost and shortest mold-cycle time while meeting the electrical, mechanical, thermal, and chemical requirements of the application. Thermoplastics and thermosets are the two main groups under which plastics are classified.

Screw-terminal connectors

Numerous types of screw-terminal connectors are available. Manufacturing a screw termination requires only a small investment in tooling, labor, and training. It is particularly advantageous where field installation requires fast and simple connections.

All wire connectors have restrictions governing the acceptable size of wires and electrical loads. Generally, nonrotating wire contacts on screw-terminated connectors handle 12 through 30 awg solid or stranded wire. Similarly, the connectors handle a variety of current capacities, making them useful in power as well as high-speed signal-handling applications.

Other types of connectors are more limited. For example, insulation-displacement connectors normally used on PC boards generally have a maximum current rating of about 2.5 A in

Choose The Perfectly Simple Precision Standard.

PS-4000 From RITTAL.

Only RITTAL provides the combination of simplicity, quality and engineering excellence your application deserves. Which should come as no surprise since we invented modular technology.

Anybody in the business will tell you. RITTAL's PS-4000 enclosures are the best engineered systems in the world. 100% of their interior space is usable. Their solid steel frames are folded nine times for a strength that surpasses all the competition. They're the most modular systems conceivable. The easiest to assemble. And the most affordable, cost-efficient systems you can buy. As for their looks, they embody the aesthetics of perfection.

Simple. Because RITTAL offers more standard, off-the-shelf solutions than anyone.

More options make PS-4000 incredibly flexible. In fact, there are RITTAL PS-4000 enclosures for virtually every industrial, electronic and data communications application. PS-4000 architecture is without limit. Its landscape infinite. Providing you with unequalled compatibility. Which means you're not going to be restricted in your design concepts. No matter how your requirements may evolve.

Simple. Because of RITTAL's new "Rilay" computerized design software.

With Rilay™, you add, modify or delete components as needed. You easily determine climate control requirements. You quickly calculate electrical, thermal and mechanical load requirements. Before you commit to a system.

Rilay™ is our ingenious computer software program that lets you design and assemble your own PS-4000 enclosures. Rilay™ displays images of RITTAL components which you then modify to suit your own specifications. You get a realistic view of the enclosure and critical information about the housing's final fit and appear while it's still in the design stage. Gettin perfect before the installation! Getting simple! Getting it fast!

Simple. Because the new PS-400 design makes it even easier to configure and install.

PS-4000 is easy. Components slide, sn or screw in place fast, without the nee

*Don't be confused by other modular systems. They don't live up to RITTAL standards. And they won't live up to yours.**

for special tools. Walls, doors, roofs and floors detach easily for unlimited access, flexibility and expansion. There are fewer parts and everything fits together for you perfectly. Simply. The first try. All because of our exacting manufacturing standards, which comply with or surpass all vital industrial protection criteria: NEMA 12/13, or even NEMA 4, IP55, UL Listed (Type 12/13), CSA Approved, VDE and DIN compliance.

Simple. Because, if you prefer, we'll assemble your system for you.
We've always provided expert assembly service. Fast. When you need it.

Simple. Because RITTAL factory enclosure experts work with you every step of the way.
You don't even have to figure out what enclosures you need. RITTAL experts will configure for you. Determining your specific needs. Making recommendations. Providing information and advice, from start to finish.

Simply stated, with all that RITTAL has to offer, why would you settle for modular systems that offer less and cost more? If you want to learn more about the PS-4000, call 1-800-477-4000 for a free brochure, and for more info about Rilay™.

RITTAL Corporation
3100 Upper Valley Pike
Springfield, Ohio 45504

RITTAL

DODO (LATIN:) *DIDUS INEPTUS.* ***a:*** An extinct, heavy, flightless bird larger than a turkey and twice as dumb. The Dodo became extinct because of his inability to adapt to changing conditions. ***b:*** The old gray control box, in modular form.

Circle 416

LAYERED ELASTOMERIC CONNECTIONS

LECs are made by stacking and bonding thin layers of nonconductive elastomer, interleaved with thin layers of conductive elastomer. Thin sheets are sliced off the resulting block perpendicular to the conductive and nonconductive layers. A typical LEC contains 250 bands or conductors per in. or more.

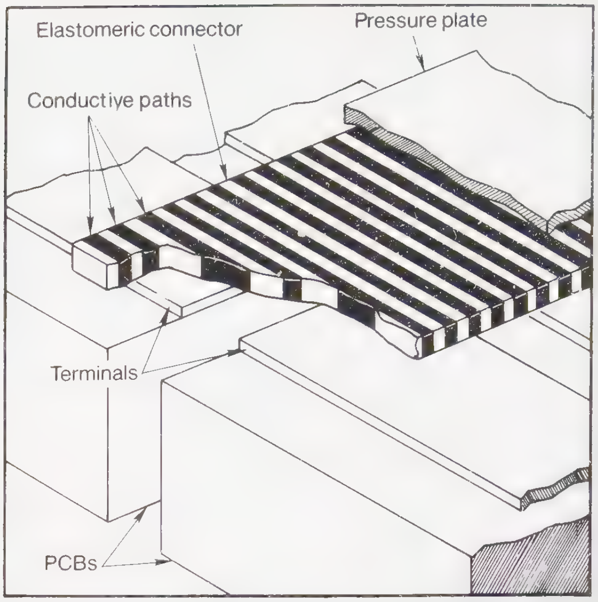
Compared to conventional connectors, the contact resistance of carbon LECs is fairly high, initially being 500 to 5,000 Ω. But resistance decreases logarithmically with time, dropping to about one-half the original level after three years. Maximum current level for these materials is about 3 mA. High contact resistance limits uses to high-impedance circuits such as those for liquid-crystal and other low-power displays.

Contact resistance of silver LECs, on the other hand, runs from about 0.04 to 5 Ω. A 5-mil-wide, 3-mil-long conductive band in a silver LEC has about 0.0 to 5-Ω resistance and carries about 0.3 A.

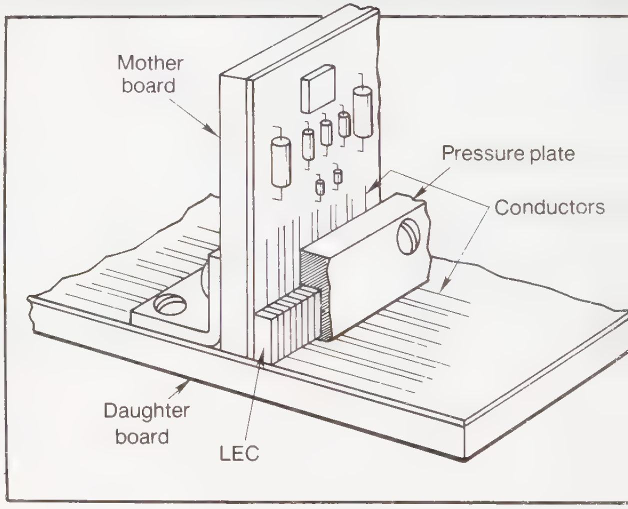
Metal-on-elastomer (MOE) connectors are constructed from thin, narrow strips of metal deposited on reinforced silicone film. The film is bonded on an elastomeric base to form a connector. Nickel is the most widely used conductor. But copper-nickel-gold stands up to corrosion better and provides lower contact resistance. Silicone rubber is the most widely used base material.

Conductors in MOE connectors are usually about 0.5 mil thick and typically 5 mil wide on 10-mil spacing. Conductors function as contact pads and as connectors between pads. But the rubber base, not the conductors, provides the spring force required to obtain and maintain good electrical contact with terminals. MOE contact resistance is about 0.005 to 0.1 Ω. A strip 5 mil in width typically can carry about 1 A.

Elastomeric connections can link terminals only 5 mil apart. They are zero-insertion-force devices and contacts can be repeatedly made and broken without wearing the connectors. Their cost can be very low for sufficiently high production quantities — typically 0.1 to 5¢ per connector terminal in quantities exceeding 100,000.



A layered elastomeric connector under light pressure provides redundant conductive paths between opposing terminals. The connector conforms to the surface of each terminal, forming hermetically sealed contacts. The compliant nature of elastomers and metal-on-elastomer connectors makes possible the interconnection of opposing terminals at differing levels.



0.1-in. centerline devices, and about 5 A in 0.156-in. centerline units. Comparable screw-terminated connectors, on the other hand, can typically handle up to 300 V at 15 A per circuit.

Screw-terminated connectors include one-piece units and two-part plug-in assemblies. One-piece connectors contain a barrier strip and accept wires that need not be soldered or attached to intermediate connectors such as crimp-on lugs.

Dual-contact fingers on some one-piece connectors provide redundant contact for reliability. Other units employ a cantilevered design that allows wires to be inserted and removed frequently without scoring the bond pads.

One-piece screw connectors also offer screw contact orientations at 90 or 45° from the board surface or parallel. The feature facilitates wiring in restricted locations.

Two-part connectors come in the form of male and female halves. The male half is soldered to the circuit board and female part serves as a socket. Wires are terminated into the female. This modular configuration permits several wires to be connected or removed with one operation.

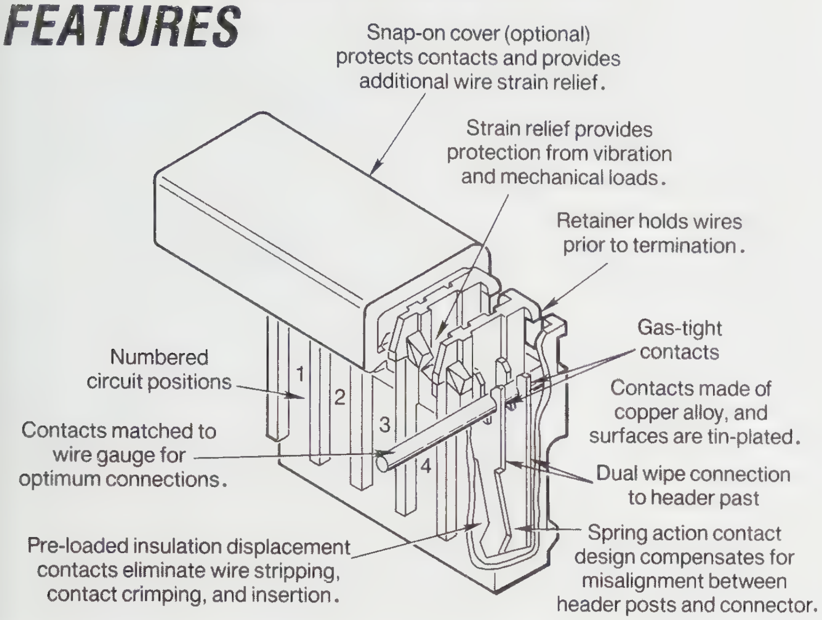
Two-part connectors are particularly convenient in assemblies needing frequent removal for field servicing. The devices minimize the chance of errors in the field because they keep wires in the correct sequence when disconnected. Typical two-piece connectors terminate between two and 20 wires.

Mechanical wire termination is the most widely used method for attaching wires to connectors. This includes clamping, riveting, cold welding, and ultrasonic bonding. However, the two most common methods are solderless wrapping and crimping.

Solderless wrapping produces a reliable gastight connection that has a large contact area with low contact resistance. The wire is wrapped around a long terminal post with a square or rectangular cross section. These posts are available on many connectors and are long enough to accept at least three wire-wrapped connections, which can be rewrapped if necessary. Stranded wire cannot be used.

Solderless-wrap connections can be made by hand-operated, semiautomatic, or automated machinery. In operation, a wire with a stripped end is inserted into the tool wrapping bit, which is then positioned over the terminal to be wrapped. The wire is wrapped around the terminal in about one-tenth of a second.

TYPICAL MASS CONNECTOR FEATURES


Snap-on cover (optional) protects contacts and provides additional wire strain relief.
Strain relief provides protection from vibration and mechanical loads.
Retainer holds wires prior to termination.
Gas-tight contacts
Numbered circuit positions
1
2
3
4
Contacts made of copper alloy, and surfaces are tin-plated.
Contacts matched to wire gauge for optimum connections.
Dual wipe connection to header past
Spring action contact design compensates for misalignment between header posts and connector.
Pre-loaded insulation displacement contacts eliminate wire stripping, contact crimping, and insertion.

Crimping requires minimal operator skill and produces consistent and reliable terminations at high production rates. Stranded and insulated wire are crimped with ease; even coaxial cable and flexible flat cable pose no serious problem. However, tooling is critical and the right combination of wire, terminal (or contact), and crimping tool is necessary for ensuring reliable joining. The cost of specialized tooling is offset by the convenience of crimped contacts in production and field repair. One tool or machine crimps a range of contact sizes through the use of interchangeable dies.

Insulation displacement connectors (IDCs) typically terminate ribbon cables, and are available with terminals matching the number of conductors in all popular cable widths. Cables are trimmed square on one end (but not stripped) and inserted into an IDC connector. All connections are then made simultaneously by squeezing the conductors into connector terminals using manual or automatic equipment.

Designs for IDCs vary widely, but all connections are based on forcing each conductor between the prongs of a split terminal. The prongs cut through the insulation and squeeze the bared conductor. The result is a high-pressure, gastight, solderless connection.

Several IDC types are available. Solder-transition connectors, for example, typically have two rows of pins on 0.1-in. spacing for direct soldering to PCBs. These IDCs generally can be soldered into PCBs either before or after a cable is terminated in the connector.

DIP plug connectors for ribbon cables generally contain from 14 to 40 gold-plated pins on 0.1 × 0.3-in. centers for inserting into standard DIP sockets. Rugged versions are available for applications involving excessive insertions and removals.

Card-edge connectors for ribbon cables join flat cables to double-sided PCBs having termination pads on 0.1-in. centers. Connectors are also available for use with European standard DIN headers. Other connectors join 0.05-in. flat cable with 9, 15, 25, and 37-pin D-type connectors with 0.545-in. spacing.

The impedance of most connectors matches that of flat cable within a few ohms. Flat cables terminated in IDCs generally are more reliable than cables terminated by other means because connections are less subject to operator skill, and wiring errors are unlikely. Flat cables, moreover, typically distinguish one edge from the other with different colors, and each fifth conductor is usually color coded, easing wire identification and troubleshooting.

Because of industry's increased concern with flame resistance, most IDC manufacturers now use plastic compounds in the connector housing that have what is called a UL 94 V-0 rating. The V-0 rating is given to material that will not support self-combustion. The ratings are assigned by testing material to UL Standard 94, a flammability test procedure.

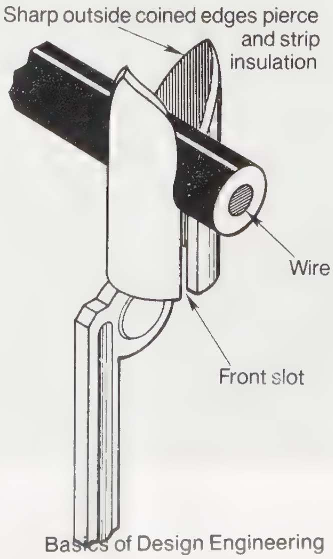
The contacts in IDCs are typically beryllium copper or phosphor bronze, but can also be brass. These metals are used for their spring qualities and ability to be plated. Beryllium copper is widely used in IDC receptacles because it responds well to forming and hardening. It is also stronger, resists fatigue better, and can withstand more insertion and withdrawal cycles than other copper-based spring alloys.

Phosphor bronze is used in IDC plugs and receptacles that do not require the mechanical properties of beryllium copper. Phosphor bronze can make a good general-purpose contact and is less expensive than beryllium copper.

Brass is used in inexpensive IDCs. It

TYPICAL INSULATION DISPLACEMENT CONNECTION

A terminal in a typical insulation-displacement connector has two slots with sharp edges that cut through wire insulation. Wires forced into the slots are deformed and make good electrical connection. The rear slot provides the greatest pressure but also produces a small upward force that subsequently, under vibration or shock, could expel a wire. The forward slot, however, is a split cylinder that produces forces normal to the surface of the wire, securing the wire in place.



is not suited for applications that require high flexibility, and can break if repeatedly stressed. However, brass is the least expensive copper-based alloy.

Plating is applied to base metal contacts to improve resistance to wear, corrosion, oxidation and/or electrical conductivity. The most common plating material is gold. Gold plating can range from a thin 1 to 3-μin. flash to a selective 30-μin. covering, in combination with tin or lead alloys. Gold plating is usually recommended for contacts that are frequently inserted and withdrawn. In addition, palladium and palladium alloy platings are sometimes used to provide a harder contact surface that resists wear.

Fiber-optic connections

Three major components in any fiber-optic system are the transmitter, receiver, and fiber cable.

Transmitters are often referred to as launchers and are usually either injection laser diodes (ILDs) or light-emitting diodes (LEDs). The total power of any launcher never completely couples into a fiber. Therefore, the power output specification of a source alone is of little help in determining available power. As an example, an LED may have a total output of 1,000 μW, but may only launch 50 μW into a fiber. This constitutes a 26 dB loss. To minimize losses, devices specifically designed as launchers contain either pigtails or special ferruled connectors. A pigtail is a short length of cable permanently fixed to the launcher. A ferruled connector consists of a special ring or nut that draws the cable up to the LED. Manufacturers using either of these methods usually list the package output power.

Receivers employ photodiodes. PIN photodiodes (positive-intrinsic-negative) or avalanche photodiodes (APDs) are often used as detectors. PINs optimize short and long wavelength response. APDs provide the most sensitivity, having a gain about 10 times higher than PIN photodiodes.

Cable optical qualities determine overall system performance. This is because manufacturers optimize cables for certain wavelengths and transmission modes. Standard cable lengths for OEMs are one and two kilometers. Some suppliers provide longer lengths. Cable originally developed for long distance telecommunications, and still used in LANs today, is designated 50/125. The material has a 50-μm-diameter core and a 125-μm-diameter cladding. It is used for its low cost and attenuation, and high bandwidth.

FIBER-OPTIC SPLICING

Fusion splicing uses a machine that incorporates a viewscope and micromanipulators. The viewscope is like a single-objective microscope. The operator uses the micromanipulators to butt the two fibers together while viewing their lateral and axial position. Once the operator is satisfied with fiber position, she pushes a button to apply heat, which first softens the fibers and then fuses them together.

One problem with fused splicing is that the procedure requires some operator judgment for success. The intensity and duration of the fusion arc must be adjusted for good prefusion softening and fusion. Otherwise, high losses and poor long-term reliability result.

Splices glued together with epoxy are usually held in position using some sort of fixture while an oven or other heating unit cures the epoxy. Some splices use ultraviolet (UV) curing epoxy that cures in sunlight.

Epoxies come as two parts that must be combined. Once mixed, shelf life is generally between 5 and 20 min. A problem with UV-curing epoxies is that they may cure too quickly to make a splice when working in sunlight. Curing times for other kinds of epoxy splices are usually on the order of 5 min.

Many manufacturers recommend the use of cables larger than 50/125. Cables with core diameters of 100 to 200 μm are widely used. The large diameters are easier to splice and interconnect and can carry more light. A plastic-coated glass fiber with a 200-μm core can transmit seven times more light than one with a 100-μm core and 65 times more than a 50-μm core.

Large fibers also have higher collection factors, making them more efficient at collecting light. Collection factors refer to the amount of incident light captured by the cable. Higher light efficiency allows the use of LEDs rather than laser launchers.

Most connectors use an epoxy/polish termination. After the fiber is stripped to the proper dimension, it is attached with epoxy to the connector. Strengthening members are then crimped to the connector body. Finally, the fiber-connector end is polished to a fine finish.

Exceptions to the epoxy/polish system are reusable mechanical splices and epoxyless connectors. Epoxyless connectors, largely developed over the past five years, are generally comparable to standard epoxy/polish connectors. They bring the applied cost of fiber-optic terminations in line with that of copper conductors.

Connectors must be functionally compatible with similar connectors, and interchangeable among the various manufacturers. For example, large telecommunications companies like AT&T in the U.S. and NTT in Japan design their system connectors to be both mechanically and optically compatible. In other cases, specifications describe the type of connector to be used, such as MIL-C-83522 for SMA-style connectors in military applications.

Each connection to a fiber incurs some light loss. Since losses add, the number of connections influences the maximum length of the system. Typical losses vary from as low as 0.2 dB for splices to about 4 dB for inexpensive connectors.

A variety of factors cause connector losses. Typical causes include variations in the fibers, such as differences in the core diameters or numerical apertures, and core concentricity.

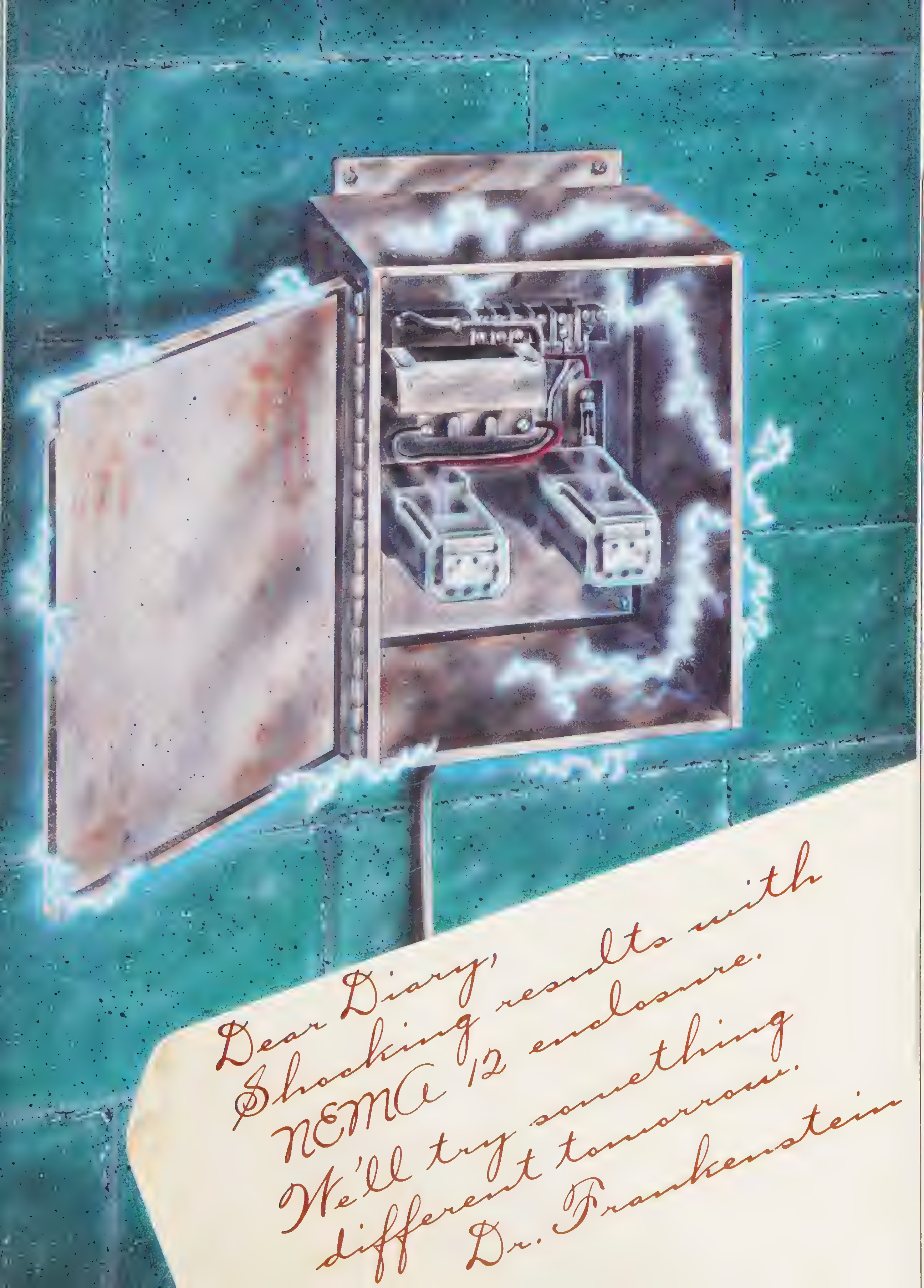
Many connectors maintain a small gap between the fibers. In some cases this gap is designed to prevent damage to the fiber end finish. But the gap causes losses from Fresnel reflection and from the spreading of light from the fiber end. To reduce these losses, some manufacturers fill the gap with a material having a refractive index close to that of the fibers.

Misalignment of the center axis of the two fibers also causes attenuation. A 10% offset from the core diameter results in a loss of about 0.5 dB. This means that for a 50-μm core, the connector must hold each fiber to within 5 μm. Most connector manufacturers attempt to limit lateral offset to 5% of the core diameter.

Angular misalignment also causes losses. For a given misalignment angle, attenuation increases as the numerical aperture of the fiber decreases.

PCB connectors

Most printed-board connectors are either a one-piece receptacle or a two-piece plug and jack. With receptacle (edge) connectors, the printed-circuit board foils extend to an edge of the board, which is mounted into the connector receptacle. With two-piece con-


Dear Diary,
Shocking results with
NEMA 12 enclosure.
We'll try something
different tomorrow.
Dr. Frankenstein

PRODUCTIVITY

Starting with a design that is 50% lighter weight than metal to reduce shipping costs and allow easier handling during installation, there are patented corner rails that allow more efficient equipment mounting on interchangeable panels at any depth in the enclosure — without drilling or standoffs. This swing-out panel system allows for additional mountings and service — a new dimension in functionality. Formed in Valox™ 357 engineering material, there are no sharp edges — a safety feature and there's no need to ground the enclosure — only the components mounted inside.

FLEXIBILITY

This new NEMA 12 enclosure design accepts existing standard metallic back panels making your retrofit jobs very easy. The variety of screw covers, hinge covers, internal covers in clear Lexan™ 950 resin from GE (which allows see-through inspection of equipment) or opaque designs come in a range of sizes to meet almost any application criteria.

PERFORMANCE

Our Circuit Safe® NEMA 12 Enclosures offer high impact strength to withstand bumps, hammer blows and up to five foot drops at temperatures as low as -35°. Compared to metal they are corrosion resistant and electrically insulative — providing safety from shock. And the unique design protects the internal equipment against hazards such as dust, dirt, oil, and chemicals. Combined with a UL94 thermal index of 120°C, they are, also, competitively priced — costing less than traditional metallic enclosures and providing a longer life.

STATE-OF-THE-ART ENGINEERING MATERIALS

Valox™ 357 resin, a high performance material developed by the R&D efforts of GE, offers high temperature and high impact properties combined with ohmeric values near zero, tensile strength of 7000PSI and a flex modulus of 300,000PSI. Simply put, it's a tough material that's been molded with design features that are not typically available in metallic enclosures.

® Registered Trademark of Carlon
™ Trademark of General Electric Company

Mounting rails for easy installation

Tapered edge design keeps liquid from cover

Cover made of Lexan™ resin provides view of internal components

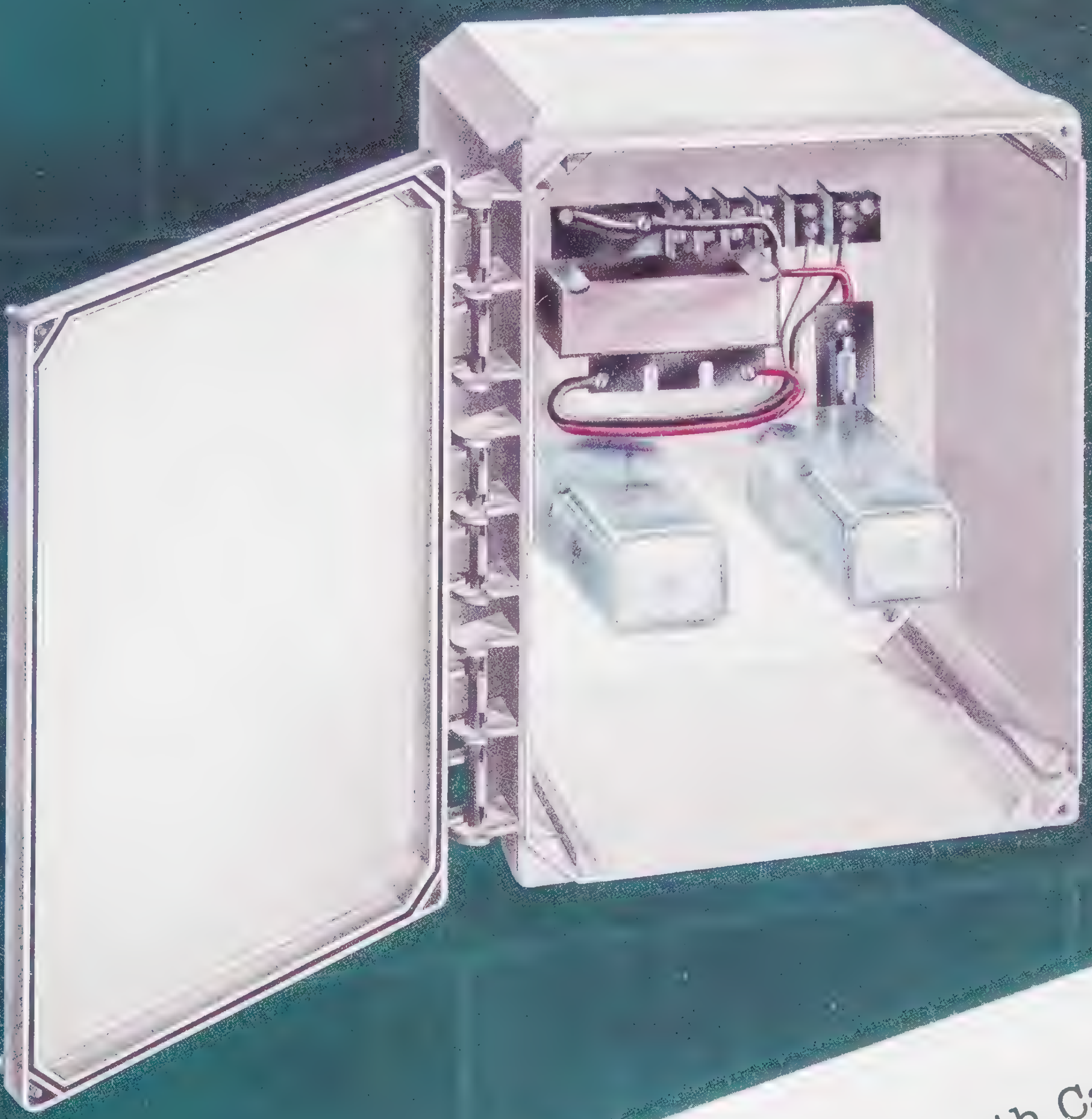
Adjustable panel guides - unique to industry

NO MORE SHOCK THERAPY

NO SHOCKING RESULTS WITH OUR
NEW CIRCUIT SAFE® NEMA 12 ENCLOSURE TECHNOLOGY . . .
ONLY PERFORMANCE,
EASIER SALES AND HAPPIER CUSTOMERS

Carlon
A LAMSON & SESSIONS COMPANY
25701 Science Park Drive
Cleveland, Ohio 44122
1-800-321-1970 (outside of Ohio)
216-831-4000 (within Ohio)

Circle 417



Dear Diary,

Another successful project with Carlon.

(Grandpa, would be proud.)

Dr. Frankenstein, III

cc: Standard Electric Supply (Milwaukee, WI)
Hughes Supply Inc. (Orlando, FL)
GE Plastics (Pittsfield,MA)

Circle 417

nectors, the connector jack is soldered or otherwise connected to the circuit-board edge and mates with a receptacle. The most widely used style of PCB plug and jack connector type is the Eurocard or DIN format.

Both edge and DIN connectors can accommodate single or double-sided board foil connections. Contact current ratings range from 3 to 7.5 A for standard edge connectors and about 1 A for the smaller Eurocard contacts. Connectors can also be polarized through insertion of metal or plastic keys which, in turn, fit into notches cut into the circuit board.

Circuit-board connectors have a variety of contacts styles, which are generally determined by the number of insertions and withdrawals expected for the board. Some high-priced contact systems provide as many as 100,000 contact matings without failure. Connectors attain these characteristics through the use of highly compliant contacts and are generally two-piece types.

When fewer than 100 contact matings are required over the connector life, one-piece receptacle connectors are generally used. These connectors contain fewer parts and materials than two-piece connectors, hence they generally cost less. Two-piece connectors are used to provide reliable connections in the presence of shock and vibration; simple one-piece connectors are often used in general-purpose applications.

Contacts: Several contacts are available in circuit-board connectors. Bellows mating uses a folded metal ribbon to maintain contact with foil areas on the circuit board. These contacts make reliable connections with boards of uneven or unusual thickness. Ribbon contacts are similar to bellows contacts but are generally less expensive because the contact has fewer folds. However, this contact has less compliance than a bellows contact, hence it has higher contact force on the board edge. Cantilever contacts have less compliance than ribbon or bellows contacts and are relatively inexpensive. These contacts often have gold areas selectively welded to the point of contact to provide very low electrical resistance.

Tuning-fork contacts squeeze the circuit board between a forklike metal extrusion. These contacts cannot handle off-size board thicknesses because the metal fork has little compliance. However, the fork's high contact force provides low electrical contact resistance. One kind of contact called hermaphroditic forks, or a fork pair, uses two forks that slot into each other to provide a large contact area and a wiping action over the entire contact length for a reliable low-resistance connection.

Four main types of connectors for bus systems are available: edge connectors, plug and socket (two-piece) connectors, ZIF (zero-insertion force) connectors, and stacking connectors.

Backplanes: Designers may choose either of two main types of buses, backplane or stacking. Standard motherboard backplane buses use one-piece edge connectors. To handle more complex circuits, designers usually prefer two-piece connectors.

Both card-edge and two-piece connectors are predominantly used with backplanes. Mating force limits the practical size of non-ZIF devices. In edge connectors, insertion force must range from 8 to 16 oz per contact to reliably connect thin boards while avoiding permanent damage to thick boards. This high force also limits edge connectors to 140 contacts or less. Most such connectors are designed for boards 0.062 in. thick and are not practical in bulkier multilayer PCBs.

Two-piece connectors overcome numerous drawbacks of edge connectors. Most versions use an 0.025-in. square pin and mating receptacle arrangement. Low tolerances minimize mating forces. Consequently, the connectors can contain up to 700 contacts. The use of pins and receptacles also allows the connectors to contain up to four rows of contacts.

Plug-and-socket connectors may cost more than other types but also require less board preparation. For example, two-piece units need no gold-plated PC pads, as do edge connectors. They also can do without the chamfered lead-ins that help guide boards into card-edge connectors.

Plugs and sockets make contact on two, or even four, sides of each male pin. The multiple contact makes the devices relatively insensitive to vibration. Edge connectors, on the other hand, rely on spring contacts that can eventually lose strength with repeated use.

Backplane connectors usually attach to a motherboard either by soldering or through use of compliant pins. These pins provide a reliable gastight connection to plated through holes on the motherboard in lieu of soldering.

To handle a large number of signals, designers often employ a split backplane. This configuration divides bus connections between two motherboards, one on either side of the daughterboards. Use of the two motherboards shortens the path of connections to daughterboards and, thus, may improve performance. One drawback, however, is that replacement of a daughterboard requires complete disassembly of the two motherboards.

It may be advantageous to employ side-entry ZIF connectors in frequently disassembled split-backplane systems. Contacts on these connectors are cammed open so daughterboards can slide into the connector. Thus, in split backplanes, ZIF devices serve as both electrical connectors and as card guides. This may eliminate other card-cage hardware and somewhat offset the higher cost of ZIF components.

Surface-mount attachment

Surface-mounted packages have short leads or no leads at all. They can house the same chips, components, or connectors as leaded methods, but in much smaller spaces. Surface-mounted components are soldered to foils on printed-circuit boards in a manner analogous to mounting hybrid circuit components. The circuit board does not need holes for component leads. Consequently, surface-mounted packages can be spaced much closer together and the board need not go through drilling operations. Also, surface-mount boards can have circuitry on both sides.

Automated manufacturing processes used with surface-mount boards demand that parts be dispensed from 8-mm tape, magazines, or from bins. Wave soldering can be used with surface-mount devices but the equipment may require modification if previously used to solder leaded parts. Solder temperature, wave size, number of waves, and feed speed parameters may also need changes.

Other techniques use solder reflow to attach parts. With reflow soldering, a solder paste is screened onto the circuit board before component placement. This paste holds the parts to the board. The board is then heated to about 210°C. The paste melts or reflows to form solder joints. Surface tension of the solder keeps the components in place.

Reflow soldering is done by infrared heating or a technique called vapor-phase reflow. Vapor-phase reflow equipment heats the solder paste using an inert fluid that boils at 210°C. Populated surface-mount boards are fed through vapor-phase equipment in a manner resembling wave soldering. Instead of passing over a wave of solder, the board passes through boiling inert vapor. Unlike wave soldering, the vapor-phase soldering process is not easily viewed. The boards are soldered inside a chamber to minimize the loss of the inert materials.

Some surface-mount attachment techniques use epoxy, which may cost less than soldering processes in certain applications. The process begins with the screening of electrically conductive epoxy onto the circuit board at attachment points. Drops of nonconductive epoxy hold larger components. Placement machines then position surface-mount devices on the board. Convective or vapor-phase heating then cures the epoxy.

The epoxy process has two key advantages. First, it consists of fewer manufacturing steps than soldering. Circuit-board foils need not be pretinned and there is no need for a solder flux removal/cleaning step. Second, conductive epoxies can minimize the effects of thermal expansion coefficient mismatch between chip and printed-circuit-board materials.

Conductive epoxies have some drawbacks, however. The material is three times as expensive as solder, and "epoxy bridges," unlike solder paste bridges, will not clear themselves when heated. Mixed assemblies are not practical because epoxy must be applied manually to through-hole connections.

Surface-mount connectors: About a dozen manufacturers now supply surface-mount connectors. Most designs are horizontal or vertical headers and receptacles. Board-to-board and wire-to-board types, including D-subminiature and card-edge connectors are common. Many suppliers also have surface-mount sockets for ICs. Specialty connectors such as fuse block or screw terminated are generally not available because the size of these connectors defeats the benefits of surface mounts.

A through-mount connector joint can distribute forces over an area approximately five times larger than surface-mounted connectors (SMCs). To compensate for the smaller area, some manufacturers hold the SMC to the board using mechanical or chemical-bonding devices such as stakes, screws, or glue. But other types of connectors rely solely on solder joints to withstand outside forces. Each method has special advantages.

Even when the solder is the only attachment used, the resulting joints have considerable strength. Strength depends on lead and solder type, the height of the lead above the board, and the quality of the solder joint. Individual joints have demonstrated tensile strengths of over nine pounds.

Depending on how the SMC is placed on the board, nonbonded connectors can often be mounted at faster rates then bonded types. And nonbonded types are often less expensive and smaller. Therefore, they are self-aligning during solder reflow.

Shielding

With the proliferation of electronics in almost every field of engineering, EMI suppression is becoming a bigger concern than ever before. But the tools needed to prevent it are vastly improved over what they were.

Electromagnetic compatibility results from reducing the noise impinging on a system below the level where the system is disturbed. Noise sources, called emitters, can be external like a radio beam, or can arise from the system itself, a problem encountered in some computers. Susceptor circuits may be remotely located from the noise, or enclosed in the same box.

Effective EMI control prevents spurious signals from entering or leaving an enclosure. Shields and filters are the predominant techniques for controlling EMI.

Shields involve more than a simple steel enclosure. Combinations of foils, conductive inks, paper, and adhesives are used to create composite materials that provide innovative solutions to packaging problems. For example, there are now shields that consist of silver ink printed on 5 mil thick polyester. After printing, a curing process removes nonconductive solvents. The result is a homogeneous shield that does not crack or delaminate when bent. The shield can be mechanically fastened and grounded with solder tabs. The cost is about the same as that for conventional laminated designs.

Plastics are not usually the first materials considered when designing an EMI-tight enclosure. But carbon and stainless-steel fibers, combined with thermoplastics, provide an effective shield in many applications. Carbon fibers are usually classified as either PAN (polyacrylonitrile) or pitch. PAN fiber composites are selected for their high strength. Also, because PAN fiber has a higher aspect ratio (length to diameter ratio) than pitch, less is needed to provide a given conductivity.

Pitch-based fibers are not as strong as low-modulus PAN fibers. However, pitch fibers process easily into high-modulus products, making them attractive for stiffness-critical and thermally sensitive applications.

The third carbon additive commonly used is carbon black. Carbon-black plastics are inexpensive, and are primarily for applications requiring high surface conductivity that allows dissipation of static charge.

Five factors affect plastic conductivity. The first is fill aspect ratio, which is proportional to conductivity. Second, is loading level, also proportional to conductivity. The lowest fill

CHOOSING MATERIALS FOR SHIELDS

One easy-to-use material for any type of RF shield, fastener, or gasket is beryllium copper (BeCu). BeCu has excellent thermal and electrical conductivity, and does not absorb moisture.

Unlike an elastomeric gasket, pressure has little effect on the SE of a BeCu gasket. Consequently, required contact forces for BeCu gaskets are ⅒ to ⅕ that needed for an elastomeric gasket. Additionally, BeCu gaskets do not compression set.

However, plain BeCu is not necessarily best for every application. For example, several situations require a plated BeCu gasket. One is on aluminum enclosures.

Aluminum enclosures are usually protected from oxidation with Irridite or metal plating. But Irridite has only fair abrasion resistance, and gaskets wear through in a short time. When the BeCu and aluminum come in contact, galvanic corrosion occurs because the two are dissimilar metals.

The solution is to plate either the enclosure or gasket. Nickel plating is recommended for enclosures, while gaskets can be plated with nickel or tin. If the enclosure is plated, the gasket need not be.

Steel enclosures also cause problems, especially when they are plated with zinc and yellow chromate. The result is a finish with good corrosion resistance but widely variable conductivity. Tests show that conductivity from batch to batch ranges by almost two orders of magnitude.

Instead of zinc, steel enclosures should be plated with tin. The reason is that while a zinc-plated gasket offers perfect galvanic compatibility with a zinc-plated case, the two together make a poor shield. Therefore, tin-plated gaskets are a better alternative. If a higher level of shielding is needed, either tin or nickel-plated enclosures combined with standard BeCu gaskets are preferred.

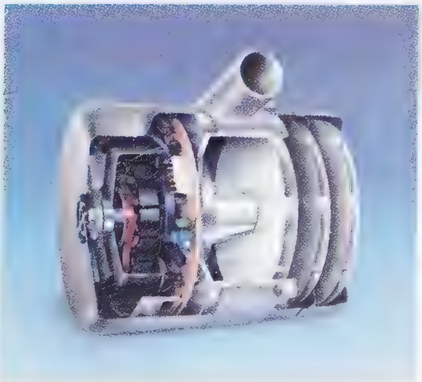
Here's technology that delivers regenerative blower performance in a fraction of the space

High air flows, high pressure capability and variable speed in a compact package

Just 5.7″ (145 mm) in diameter by 5.2 to 7.2″ (132 to 183 mm) long, these Windjammer® blowers combine brushless motor drives that provide high speed, high torque and controllability with high performance fan systems. They're much smaller, weigh only 10% as much and are 25% more efficient than a regenerative blower with comparable performance. The result is a compact, cost-effective blower for demanding applications such as medical equipment, business machines and materials handling.

Application matched performance

Windjammer blowers are available with 1-, 2- or 3-stage fan systems. Their bypass design provides a separate fan for motor cooling and adapts to a wide variety of applications. These blowers can be optimized for high air flow of up to 125 cfm (212 m^3/hr) free flow or high pressure/vacuum capability of up to 75″ H_2O (185 mbar) sealed.



Models for worldwide AC operation

These Windjammers feature integral power conversion with models available for operation from any standard AC input power. With one version, a 0 to 10 VDC signal from a sensor or other device will control motor speed and adjust air performance from 0 to 100%. Or, a second model provides manual speed control by means of a potentiometer located in the blower housing.

Windjammer blowers are UL component recognized, CSA and TÜV certified. Complete specifications are available from AMETEK, Lamb Electric Division, 627 Lake Street, Kent, OH 44240. Tel: 216-673-3451. Fax: 216-673-8994.

AMETEK
LAMB ELECTRIC DIVISION

Circle 418

loading needed to produce conductivity (generally defined as 10^5 Ω/sq) is called the critical concentration.

The third factor is resin type. The amount of fill needed for the critical concentration depends on the resin. For example, because nylon has a crystalline structure, its surface becomes conductive at lower fill concentrations than materials such as amorphous polycarbonate.

Processing method is the fourth factor. Improper processing can decrease fill aspect ratio. Finally, the conductivity of the fill itself also affects compound conductivity.

Several EMI blocking thermoplastics are available. One uses nickel-coated PAN carbon fibers. Nickel coating increases conductivity by up to 50 times. At 15% loading, the fibers have a conductivity equal to that of a 50% loading of uncoated fibers.

Another is based on stainless-steel fibers. These composites have conductivities equivalent to those of PAN, but at significantly lower percent weight concentration. As a result, the mechanical or processing characteristics of the resin base remain relatively unchanged. Polymers with 5% stainless steel can provide up to 40 dB of attenuation. And unlike other additives, stainless-steel fill allows enclosures to easily meet color specifications.

A common problem in enclosures is large area openings needed for displays or ventilation. While heavy screens can provide effective EMI shielding for ventilation holes, they often interfere with the optical characteristics of displays. Thus, manufacturers have devel-

DESIGN FOR EMC

Electromagnetic compatibility (EMC) standards depend as much on mechanical design as they do on electrical design. In fact, EMC is largely set by the methods used to finish, fasten, and assemble structural parts made of metal. Poor electrical contact between these parts can lead to excessive radiated EMI and a susceptibility to interference and electrostatic discharge (ESD).

Whether a structural components is used for grounding or shielding, preferred practice is to minimize electrical impedance at the mating surfaces. But metals naturally form oxide films or are protected by special coatings, and these films increase electrical impedance at the joints. As a result, mating surfaces must be designed so that oxides are broken or removed during assembly, exposing virgin metal. To limit further corrosion buildup, joints must be gas tight to seal out moisture and they must also be mechanically stable to prevent parts from loosening under shock and vibration.

One way to break through the oxide layer when joining parts is to use a star washer or a serrated surface along with the high normal force of a bolt and nut. Special fluids or lubricants can also be applied to contact points to inhibit the corrosive action of electrolytes. Another precaution is to coat mated joints with paint or other finish to seal out moisture.

Mating metal parts also must be galvanically compatible, having minimal electropotential difference. Metals or platings from the middle of the galvanic table usually provide the best results because they have low electropotentials and any difference is small. Tin is a good starting choice because its natural oxide is easily broken and it plates and solders readily. Stainless-steel hardware is a poor choice because it is strongly anodic compared to tin and most other metals.

Structural parts should be grounded through uniform low-impedance paths. Otherwise they can develop voltages relative to other "grounded" parts. A potential difference between two metallic parts of any shape forms an electrical dipole that can radiate an electric field. If the source of the potential is at radio frequencies, the field can interfere with nearby electronic circuits. In some cases, poorly grounded cable shields act like antennas and transmit EMI signals.

Products that contain printed-circuit boards often use the outer structure as a "ground reference." Boards are typically attached by standoffs that also provide a ground path to the structure. But ground current flowing in the structure can cause problems if it hits high impedance at the joints. Potential differences across these impedances set up the conditions for radiated electric fields.

Ground wires or straps are sometimes used as a last resort to improve the connection between two components or assemblies. However, to be effective at radio frequencies, the strap's length should be no more than three times its width. In general, all current-carrying elements, including standoffs, should be short and wide rather than long and narrow.

Although ground straps are usually made from heavy copper wire or braid, they still present RF impedance. Most wires have about 12 to 28 nH of inductance per inch. Using a nominal value of 20 nH, the reactance per inch at a typical EMI frequency of 100 MHz is approximately $2\pi fL = 12.6\Omega/$in., where f = frequency and L = inductance.

To lower net inductance and reduce ground potential differences, multiple straps are recommended over single straps. Net inductance roughly equals that of one strap divided by the number of straps. As in single connections, the overall width-to-length aspect ratio should be 3:1 or less.

Grounding precautions to minimize RF emissions also lessen the effect of ESD. The reason is that low-impedance ground paths allow ESD currents to pass around rather than through electronic circuits. Also, because all metal parts are uniformly grounded, potential differences caused by ESD current are minimal.

In many applications, structural enclosures also provide electromagnetic shielding. These shields are usually made from high-conductivity, nonferrous metal such as aluminum or copper. The materials are effective because they readily allow induced eddy currents to create a field that opposes and cancels the incident field.

If the shield has holes or gaps, however, they will impede the induced currents, and the incident field might not be completely canceled. What's worse, current flowing around an obstruction acts like a small loop antenna, effectively transmitting RF leakage.

The problem is that slots form whenever two pieces of metal are joined and their connection is not continuous. Slots are present even in overlapping sheet metal. Slot length, rather than width, largely determines the amount of leakage, and it should be no more than one-tenth of a wavelength at the highest frequency of interest.

One way to close slots in shields is to use RF gaskets. These gaskets, commonly available as multifingered spring clips or woven braid, fill slots and gaps with metal to provide many points of electrical contact. Wiping or abrading action during assembly breaks through oxide films on the mating surfaces and ensures good electrical contact. Serrated lockwashers also help.

The benefits of multiple ground straps also apply to shield joints. A rule of thumb is to space fasteners no more than 0.10 to 0.15 wavelengths apart. Wavelength at 1,000 MHz, which meets regulatory shielding requirements for most computing equipment, is $c/f = 30$ cm, where c = speed of light. This shows that shield-joint fasteners should be less than 3 to 4.5 cm apart. However, experiments can help determine their optimum number and placement.

FOR A COMPLETE PEM® FASTENER CATALOG

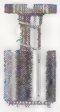
ear it out ▽ Fill it out ▽ Fax it out!

Self-clinching floating fasteners compensate for mating hole misalignments. Available with locking or non-locking threads.

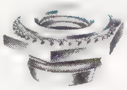
Self-clinching flush fasteners remain flush on both sides in panels as thin as .060" (1.5mm).

Self-clinching, concealed head studs and standoffs are installed into milled, blind-holes. Ideal for applications where the surface opposite the fastener must remain unmarred.

Self-clinching KEYHOLE® standoffs accurately space P.C. boards or components from metal chassis. Designed so that a panel can be quickly slipped into place and then removed by sliding the board sideways and lifting it off.



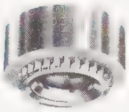
Self-clinching, self-locking fasteners provide prevailing torque performance meeting MIL-N-25027 requirements.



Self-clinching panel fastener assemblies are completely pre-assembled and spring loaded. Available in standard and black finishes.

Self-clinching nuts provide strong internal threads in sheets as thin as .030" (0.8mm). Also available for installation in stainless steel.

Self-clinching blind fasteners provide blind threads in metal sheets as thin as .040" (1mm). Commonly used to provide barriers to protect threads against foreign matter and circuits from intrusion of extra long screws.



Broaching fasteners are designed for mounting into P.C. boards. Nuts, studs, standoffs, and panel fasteners are available.

Self-clinching standoffs are available with blind or thru-threads for stacking or spacing circuit boards and components.

Self-clinching studs provide strong external threads in sheets as thin as .020" (0.51mm). Also available without threads for use as permanently mounted pins.

Self-clinching SNAP-TOP® standoffs accurately space a P.C. board from another board or metal chassis without threads. Simply snap the board on for secure attachment.

own above are just some of the PEM fasteners outlined in our complete PEM fastener catalog. If you would like more in
oth specifications on these and other PEM self-clinching fasteners, simply tear this page out, fill in the information below
d fax it to us. **We will have a catalog sent to you within 24 hours.**

AME ______ TITLE ______

OMPANY ______

DDRESS ______

ITY ______ STATE ______ ZIP ______

OUNTRY ______ PHONE ______ FAX ______

RODUCT(S) MANUFACTURED AT THIS LOCATION ______

THER COMMENTS/REQUESTS ______

FAX TO:

215-766-0143

PEM® PENN ENGINEERING & MANUFACTURING CORP.
Danboro, PA 18916-1000

CLINCH IT WITH PEM

FASTENERS & PRESSES

©1991

oped special shielding windows. One type of window is a fine conductive screen laminated between glass or plastic sheets. Another is a screen cast within a plastic sheet. The third consists of glass or plastic with a transparent conductive coating such as indium-tin oxide.

Until recently, screen mesh density ranged from 30 openings/in. for 0.001-in.-diameter tungsten wire to 10 openings/in. for 0.0045-in. wire. The screens are knitted on machines originally developed for the textile industry and modified to handle wire. Shields of this type provide about 60 dB of attenuation at frequencies below 10 MHz.

Higher density screens have greater high-frequency attenuation, typically 60 dB at 1 GHz. These screens are woven rather than knitted, and the wires are often smaller than 0.005 in. in diameter. The screens use silver-plated stainless-steel wires; copper-plated stainless-steel wires; and copper wires. Meshes range from 80 to 150 mesh.

Shielding considerations extend beyond the enclosure itself. EMI can be radiated from cables entering or leaving the case. For example, digital signals from a microprocessor can be radiated through analog I/O channels. Digital signals in backplanes and buses commonly operate at frequencies of 10 to 50 MHz, and have high-frequency harmonics. Because computer analog I/O operates at relatively low frequencies, these signals are not interfered with. However, the analog cables can radiate radio frequency energy, causing interference problems with other equipment in the system.

Another common problem is crosstalk between cables. Crosstalk is either capacitively or inductively coupled. Capacitive coupling is caused by stray capacitance between emitter and susceptor, and between susceptor and ground. Noise across the capacitors is reduced by decreasing capacitance between source and susceptor, or by increasing capacitance between susceptor and ground. Solid shields are generally superior to braided shields because capacitance can escape through the holes in braided types.

Inductive crosstalk is induced by magnetic flux between the noise and susceptor circuits. However, because permeability decreases with both increasing frequency and field strength, effective shielding at high frequencies is difficult.

Sometimes, cable-related EMI problems are not found until a system is installed. In the past, the only way to eliminate such problems was to replace the cable. Now several shields use a zipper closure to minimize interference and crosstalk. A dielectric spacer is inserted between layers of stacked ribbon cable, forming a sandwich. A shielded jacket covers the sandwich. Some jackets use a tinned-copper grounding braid attached to the inside of the jacket overlap. Zippertubing offers an almost leakproof seam. Together, the techniques can attenuate crosstalk by reducing capacitive coupling and serving as a current sink.

Enclosures

Electronic enclosures come in a variety of configurations. Products include modular frames and assemblies, instrument cases, standard rack panels, blowers and fans, solid-side cabinet racks, desk cabinets, and more. Many options and variations are available. Other enclosures include vertical and sloped front cabinets, turret frames, panel handles, casters, cable retractors, and blank chassis.

Three organizations have published electrical enclosure standards for U.S. industry.

- Underwriters Laboratories Inc. (UL) standards for electrical enclosures formerly included requirements for just one enclosure type for indoor applications, and two enclosure classifications for outdoor applications. Other UL standards are for various hazardous locations defined by the National Electric Code.
- The National Electrical Manufacturers Association (NEMA) enclosure standards include a series of classifications designated by arbitrarily assigned numbers. The enclosures are intended for use in specific industrial environments to provide both mechanical and environmental protection. The types are defined by a statement of the intended application, performance tests, and specific design features. Over the years, the number of classifications has expanded to include 18 different types.
- The now defunct Joint Industrial Council (JIC) left its mark by establishing many of the specific design features that still exist in many Type 12 enclosures, pushbutton enclosures, "JIC" boxes, etc.

As a result of efforts to reach concurrence, UL and NEMA enclosure standards now include many of the same types. The exception is Type 5, which at one time was superseded by Type 12, but has since been reinstated.

Although the requirements for NEMA and UL are nearly the same, at least two significant differences still exist. Both concern the degree of corrosion protection required. For most enclosure types rated for outdoor applications, UL requires one of several alternate methods of corrosion protection. NEMA requires only the same protection as specified for indoor enclosures. (NEMA's logic is that additional finish requirements may be imposed by others as appropriate for each intended environment.)

Another difference is that UL does not clearly distinguish the corrosion protection requirements for Types 4X and 6P from those for other outdoor enclosures. However, NEMA requires a greater degree of corrosion resistance equivalent to Type 304 stainless steel when an enclosure is subjected to a 200-hr salt spray test.

Enclosure standards originating in other countries are significant to U.S. firms involved in foreign trade. Important examples are those published by the Canadian Standards Association (CSA) and the International Electrotechnical Commission (IEC).

CSA functions similarly to UL. It is a nonprofit, independent organization composed of representatives of a wide range of occupations formed to develop industrial standards. CSA offers product testing and certification together with follow-up checking at client's factories. Certification by CSA is increasingly necessary to market products in Canada. IEC is an international agency that publishes industry standards widely accepted in Europe and other parts of the world. The IEC has no enforcement powers; certification is performed by each nation's testing agency.

Modular enclosures: Many electronic enclosures now come in what is called a modular format. Large cabinets are made by simply joining smaller units together. Shipping costs are reduced because the enclosure units are handled easily, which also reduces damage claims and labor costs.

Electrical equipment is usually mounted to a back panel while electronic controls and instruments can be mounted in several ways. Electronic components can be mounted to racks, placed on shelves, or on roll-out surfaces. Other accessories include writing surfaces, print pockets, drawers, casters, levelers, and eye bolts for lifting.

Some enclosures also are sealed well enough to qualify for NEMA-4, 12, or 13 ratings, providing indoor and outdoor protection from falling, dripping, or spraying noncorrosive liquids. Most enclosures have a NEMA-1 rating, providing protection only from contact with enclosed equipment and, to some degree, against falling dirt. Some modular cabinets use welded frames made

BASICS OF ENCLOSURE COOLING

The methods for dissipating heat from enclosures can be grouped into two categories: those that maintain the NEMA-4, 12, or 13 rating, and those that do not. Fins, a heat exchanger, or an air conditioner can be added to the cabinet to maintain a strict NEMA rating. If the rating is not critical, vents or fans with filters can be added.

Maintaining the rating: A cabinet with no active method of heat dissipation will still pass internal heat to the atmosphere by convection and radiation. The internal temperature rise can be calculated by the following steps:

1. Heat generation Q within the cabinet is found by summing the heat dissipation of components, rather than their power consumption.

2. Exterior surface area of all six sides of the cabinet is $A = (2dw + 2dh + 2wh)/144$, where A = area, ft^2; d = depth, in.; w = width, in.; and h = height, in.

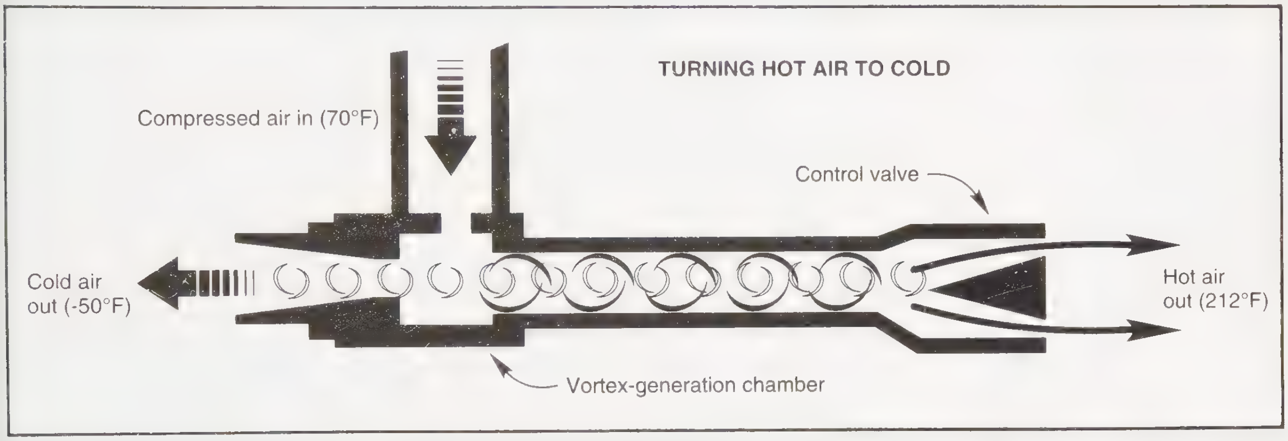
3. Temperature rise within the cabinet is approximately $\Delta T - 4.08\,(Q/A) + 1.1$, where ΔT = temperature difference between inside and ambient, °F; Q = heat generated within the cabinet, W; and A = cabinet area, ft^2. This expression is valid for a wide range of ambient temperatures.

For example, a cabinet that generates 1,200 W of heat and has an area of 55.6 ft^2 (22 in. × 25 in. × 74 in.) can be expected to have an internal temperature rise of $\Delta T = 4.08\,(1{,}200/55.6) + 1.1$ or about 90°F. If ambient temperature is 72°F, internal temperature can rise to about 162°F. If the same equipment is mounted in a cabinet twice as wide (d = 44 in. or A = 85.6 ft^2), a temperature rise of about 59°F and a more tolerable internal temperature of about 130°F can be expected.

Heat dissipation by fins is complicated by thickness, shape, and spacing. Generally, fins can improve heat dissipation by convection, which accounts for about 45% of the total heat loss. Consequently, the area off the cooling fins must be large to have an appreciable effect on cabinet temperature. Fins should be attached with good surface contact and they should be oriented vertically so as not to inhibit airflow over them. Fin height should be no more than four times fin spacing.

Heat exchangers can use a refrigerant as their heat-transfer medium or can be an air-to-air type that involves an aluminum structure with fans to each of two closed circuits, one for internal air and one for ambient. Air-to-air heat-exchanger performance can be calculated from $\Delta T = Q/(q + kA)$, where q = thermal-transfer capability of the heat exchanger, W/°F; and k = heat-dissipation coefficient for painted sheet steel, between 0.26 and 0.31 W/°F-ft^2. If a heat exchanger that dissipates 6 W/°F is attached to the example enclosure, a temperature differential of about 55W/°F with an internal air temperature of about 133°F can be expected.

Air conditioners have the added advantage of removing humidity from the enclosed space. Their performance can be calculated from $\Delta T = (Q - Q_a)kA$, where Q_a = cooling capacity of the air conditioner, W. Many U.S. air conditioners are rated in Btu (really Btu/h), which can be converted to W by multiplying by 0.292. Therefore, a 2,000-Btu unit will dissipate about 584 W. Continuing the example, $\Delta T = (1{,}200\text{-}580)/(0.285)55.6 = 39°\text{F}$, which yields an internal air temperature of about 111°F.



TURNING HOT AIR TO COLD

A vortex tube forces compressed air through a vortex-generation chamber, spinning air at sonic speeds to 1 million rpm. Some air exits through the relief valve at the hot-air exhaust, while the remaining air is forced back through the center of the airstream. The return air spins at a slower speed, which sets up a simple heat exchange. Eventually the chilled air column exits the cold-air exhaust.

Vents and fans: If NEMA rating is not critical, cooling can be provided simply with a vent or fan. However, it is difficult to predict the temperature drop produced by a vent. To select a fan, calculate temperature drop from $\Delta T = 3.1\,Q/V$, where V = fan flow rate, cfm. From the original example, if a 300-cfm fan is considered, $\Delta T = 3.1(1{,}200)/300 = 12°\text{F}$, for an internal temperature of about 85°F.

This is very approximate because the pressure drop produced by the fan, usually measured by the manufacturer, should match the pressure drop produced by the airflow through the cabinet. This second pressure drop can be measured with a manometer on a full-size model of the equipment.

Compressed-air cooling: If factory compressed air is available near an enclosure, vortex tubes may provide adequate cooling. These devices can produce chilled air (-50°F) from 70°F, 100-psig compressed air, with a refrigeration rating to 6,000 Btu. Vortex tubes use no electricity nor Freon, and they have no moving parts. They also meet NEMA and JIC requirements for enclosures. A five-micron filter is required, however.

HOW TO SELECT A HEAT SINK

Choosing a heat sink depends on several factors, such as power dissipated by the semiconductor device, ambient temperature, air velocity (forced convection), and insulators between the device and heat sink.

First, consider the basic heat-transfer mechanism. Heat is generated in semiconductor junctions, conducted to the case, then to the heat sink. Finally, the heat moves from sink to ambient air. Each interface produces a temperature gradient or thermal resistance to heat flow, expressed in °C/W.

For example, the amount of heat generated in a dc voltage regulator is a function of the power it dissipates: $P_d = V_d I_d$, where V_d = voltage drop across device and I_d = current through device. The worst case is $V_d = V_{in(max)} - V_{load}$, where $V_{in(max)}$ = maximum input voltage and V_{load} = load voltage.

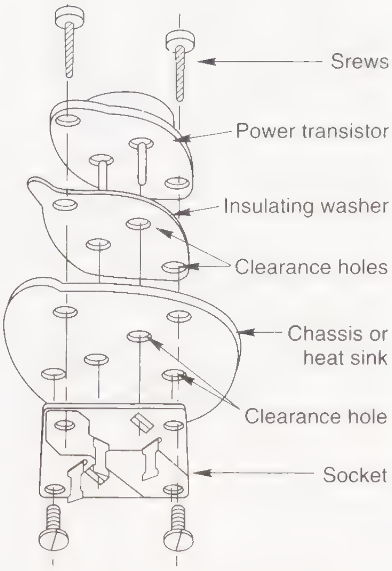
The sum of all individual thermal resistances, θ_{ja} (junction to ambient) is a measure of heat-flow thermal efficiency: where $\theta_{ja} = \theta_{jc} + \theta_{cs} + \theta_{sa}$, where θ_{jc} = junction-to-case, θ_{cs} = case-to-sink, and θ_{sa} = sink-to-ambient thermal resistances. The product of P_d and θ_{ja} yield the temperature rise of the junction above ambient: $T_j - T_a = P_d \theta_{ja}$, where T_j = junction temperature and T_a = ambient temperature, °C.

Junction-to-case thermal resistance θ_{jc} is determined by semiconductor die geometry and thermal conductivity, the bond between die and mount, and the thermal resistance of mount and interconnecting leads. Power semiconductor specifications always state θ_{jc}; however, different devices in the same case type can have very different θ_{jc}. For example, the widely used TO-3 package can range from 0.5 to 6.0°C/W, depending on the manufacturer specifications.

Case-to-sink thermal resistance θ_{cs} depends on contact area, flatness, finish of mating surfaces, insulators, and thermal conductivity of compound between interfaces. Because air is a poor heat conductor, thermal joint compounds should be used between interfaces. The compound fills voids in surfaces that are not microscopically smooth, substantially improving heat flow. By constrast, dry insulators usually increase θ_{cs}.

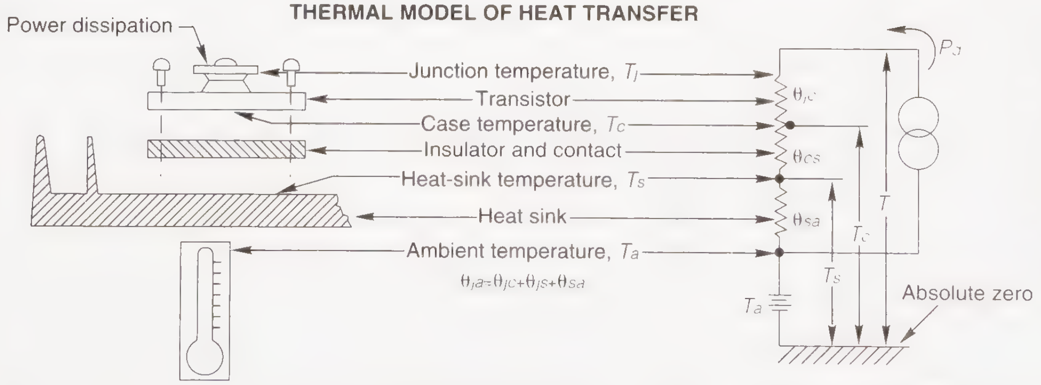
The final element in the thermal model is θ_{sa}. For a given heat sink, θ_{sa} varies with device power dissipation and ambient airflow. An increase in P_d decreases θ_{sa} because at high power levels, sink temperature rises and heat flow becomes more efficient. Heat dissipation is also improved by increasing forced airflow over the sink.

POWER DEVICE MOUNTING



A convenient method for mounting power transistors includes an insulator that electrically isolates the case from the chassis or heat sink without substantially increasing the thermal gradient. In some cases, the washer can be eliminated and the entire heat sink electrically isolated from the chassis.

THERMAL MODEL OF HEAT TRANSFER



The thermal to electrical analogy depicts a circuit that supports Kirchoff's Law. This analogy is the basis of the thermal equations used to calculate temperature gradients.

with a 14-gage, fourfold beam. Enclosures can be bolted together side-by-side for larger cabinets.

Cabinets for electronic components are 19 in. wide, recognized as an international standard. Frames are generally 11-gage steel and limited to side-by-side mounting with few internal options.

One UL-approved line of welded steel multidoor cabinets now provides removable side panels to allow union with other cabinets. Designers can build large enclosures many meters long that meet UL and NEMA specifications by bolting enclosures together, and sandwiching a neoprene seal between them. Consoles are also available in different widths and basic unit shapes that can be mixed and stacked in many combinations. Typical are a base unit, consolet (writing surface), and top unit (similar to base unit, but with an inclined front door). Base and top units include provisions for optional accessory mounting. Panels, shelves, chassis guides and drawers as well as 19 and 24-in. rack-mounting angles from a standard line of options allow specialization of the cabinets.

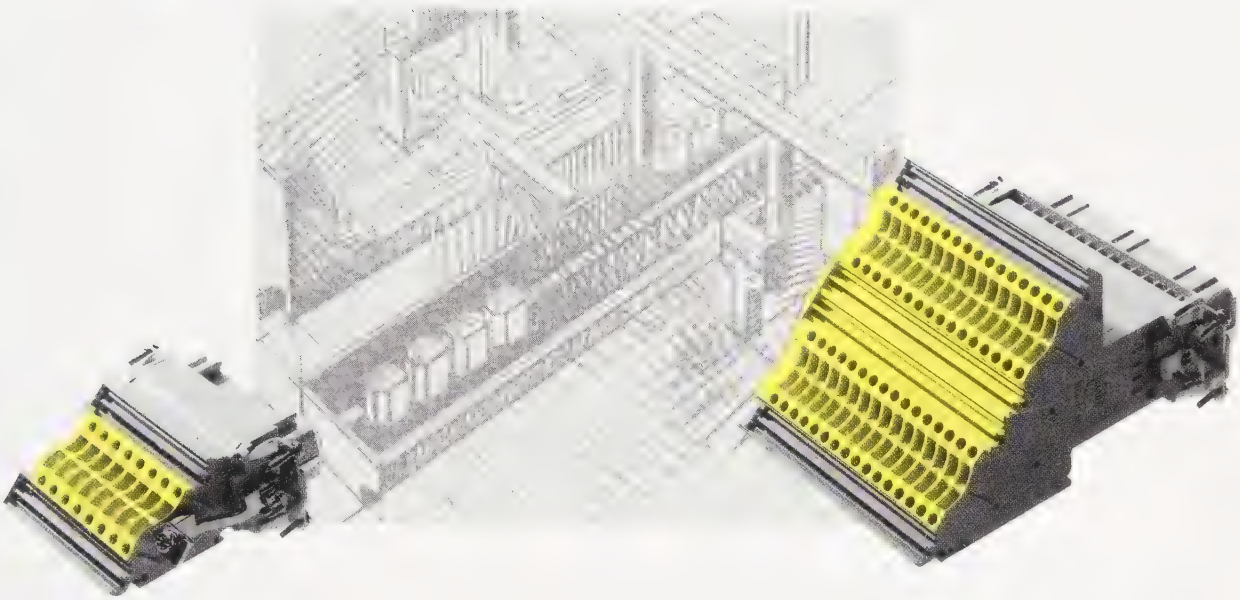
Rather than welding the corners of the cabinet frame, the uprights in other types of cabinets are tabbed to fit into slots in the cabinet top and base. Corners are then bolted for a positive connection. The bolt-together approach also means that if a side brace is damaged, it can be removed and replaced.

Air movers

Air movers can be generally classified as fans or blowers. Fans are usually axial fans or propellers that produce low-pressure air movement. Blowers,

Han® External Distribution Terminals

Compact technology, easy assembly



Optimal solutions in engineering come into being wherever development is based on a direct exchange of information with the customer.

Consequently the Han® External Distribution Terminals from HARTING are not only the result of many years of experience in manufacturing electromechanical components, but also the fulfilment of practical requirements. With a compact design, it is a connector and terminal block all in one. The arrangement of features permits trouble-free access for the test prod and optimal legibility of terminal labeling due to 45° positioning. Used as a monoblock it can be mounted in standard bulkhead-mounting housings from the cabinet side.

Han® External Distribution Terminals from HARTING – a perfect single-source range.

We shall exhibit
Productronica 91
Munich, 12 to 16 November
Hall 20, Stand 20 C 08

Connectors from HARTING – the quality connection

HARTING

HARTING ELEKTRONIK, Inc. · 2155 Stonington Ave. · Suite 212
P.O. Box 95710 Hoffman Estates, Illinois 60195, U.S.A.
Phone 708 / 519-7700 · Fax 708 / 519-9771

Circle 420

on the other hand, are usually centrifugal devices that deliver air at a higher pressure, usually for a process such as a reaction, as well as cooling.

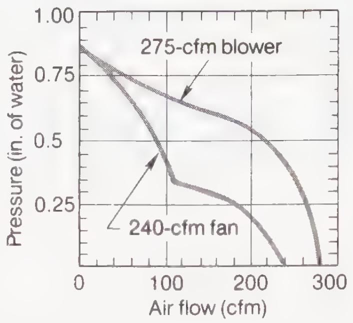
Because heat exchangers are most often available with fans, the following discussion deals with fan sizing for enclosures with heat sources. For a discussion of heat exchangers, see *Fluid Power Components.*

When fans are used to cool enclosures, they either draw air through the cabinet, or move it through an air-to-air heat exchanger. Although heat exchangers do not mix inside with outside air, they do pass heat to the environment. However, the technique isolates outside dirt and debris from sensitive components within the heating system.

An airtight cabinet without a fan can dissipate heat but may require a large enclosure for a minimum temperature rise. Adding a fan improves the cooling process over convection and radiation alone by up to tenfold.

Air filtration: When a fan is required for enclosure cooling, a washable air filter at the incoming air stream is recommended. When using air filters, a plenum must also be used to separate the fan from the filter and to maintain even, effective airflow. If a plenum is not used, the filter is placed against the fan reducing filter efficiency because 90% of the airflow passes through the tips of the fan blade.

TYPICAL PERFORMANCE CURVES



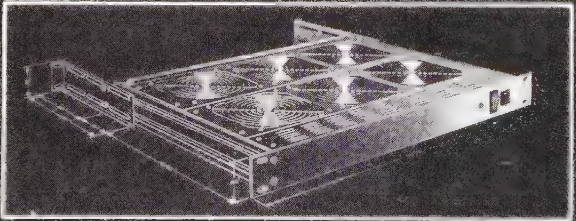
Fan location: Carefully positioning the fan in the cabinet can avoid some common cooling pitfalls. First, placing a hot component, such as a transformer, in the incoming airflow may seem good for the transformer but subjects other components to unwanted heat. If possible, hot devices should be located near the exhaust so that their heat dissipates directly to the outside.

Also, because axial fans have relatively low static pressure, their exhaust grill is often sized too small. To be safe, the size of the opening should be about 1.5 times the fan area.

Manufacturers recommend placing the fan at the air inlet for three reasons. First, maintaining a positive pressure within the enclosure helps keep dust and dirt out when the cabinet is unsealed or frequently opened. Second, a blowing fan produces turbulence, which improves heat transfer within the cabinet. Lastly, fan life is prolonged when in the path of coolest air.

Fan sizing: In most cases, the relationship between pressure and flow is described by $P = \rho k Q^2$ where P = static pressure drop, ρ = air density, and Q = airflow rate. Typical performance curves reveal the relationship between fan pressure and flow rate. Because flow rate is inversely proportional to resistance, decreasing resistance allows use of a smaller, less-expensive fan. Also, when multiple fans are used in an enclosure, they should be of the same size.

CATALOG OR CUSTOM, McLEAN DELIVERS QUALITY COOLING SOLUTIONS

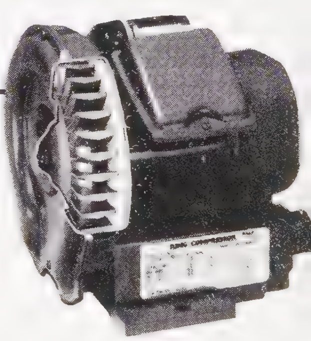


McLean can meet your cooling challenge with the most comprehensive line of cooling products, designed for superior performance and OEM production efficiency. Call, write, or bingo for our new Catalog 292. McLean is Air Cooling Technology! SEE OUR CATALOG IN THOMAS REGISTER PAGES 6844-6847

ZERO McLEAN ENGINEERING
70 Washington Road, Princeton Junction, NJ 08550
(609) 799-0100 • FAX (609) 799-1081

Call me, I'm interested: Circle 71
Send Catalog: Circle 72

Quiet. Blowers at work.



Our regenerative RING COMPRESSORS run at a whisper. And they offer high performance for more years than you can imagine.

Units are immediately available and prices are pleasingly low.

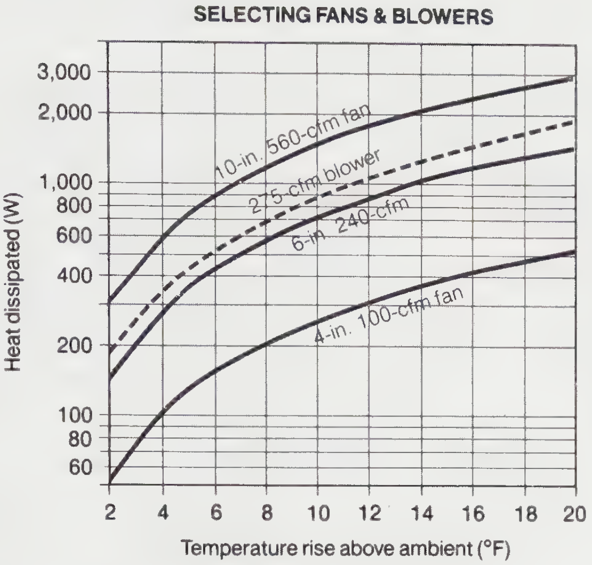
- HP from 1/10 to 20
- Pressures to 5 PSIG
- Vacuum to 110″ H_2O (8.2″ Hg)
- Flows to 570 SCFM
- UL recognized; CSA certified

Call or write for catalog, applications literature and prices.

The World Leader in Regen-Blowers
Fuji Electric Corp. of America
6A Frassetto Way, Lincoln Park, N.J. 07035
Phone: (201) 633-9000 FAX: (201) 790-0765

Circle 421

Performance curves help select a fan or blower for forced-air cooling system. To use the graph, find the heat dissipation required for the enclosure. Then, select a fan based on the temperature rise over the assumed ambient air temperature.



Fan size can be determined using a graphical approach. First, estimate the amount of heat, in watts, that must be dissipated. Then, on the accompanying fan selection graph, select a fan based on the amount of temperature rise over ambient allowed within the enclosure.

Another technique for fan sizing calculates required flow rate for a given temperature rise. The minimum airflow is found with $Q = fW/(T_{out} - T_{in})$ where Q = flow rate, cfm; f = flow factor and is the product of air density and specific heat; W = internal heat generated, W; T_{out} = exhaust air temperature, °F; T_{in} = ambient air temperature, °F. At sea level, $f = 3.1$; at 5,000 ft, f is about 3.6.

System impedance: Resistance to airflow within an enclosure (impedance) is expressed as static pressure, which is a function of flow rate. For most applications, impedance is estimated with $P = pKQ^n$ where K = load factor and n = turbulence factor (usually 2).

Basic fan laws

Variable	When speed changes	When density changes
Air Flow Q	Varies directly with speed ratio ω = fan speed, rpm $Q_2 = Q_1\left(\frac{\omega_2}{\omega_1}\right)$	Does not change
Pressure P	Varies with square at speed ratio $P_2 = P_1\left(\frac{\omega_2}{\omega_1}\right)^2$	Varies directly with density ratio $P_2 = P_1\left(\frac{\rho_2}{\rho_1}\right)$
Power W	Varies with cube of speed ratio $W_2 = W_1\left(\frac{\omega_2}{\omega_1}\right)^3$	Varies directly with density ratio $W_2 = W_1\left(\frac{\rho_2}{\rho_1}\right)$

Comair Roton

In complex systems, impedance may be found most easily by measuring the static pressure with a candidate fan. Using the estimated impedance value, the fan's static pressure vs. airflow graph determines whether the fan is suited for the application. ■

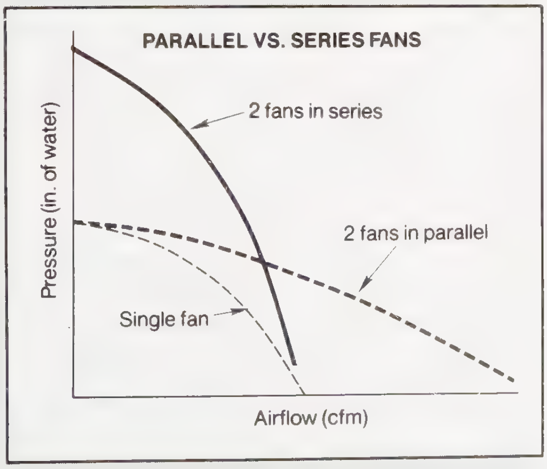
FAN OPERATION IN SERIES AND PARALLEL

Using two or more fans in series or parallel may be a better alternative than a larger fan. First of all, two identical fans are usually less noisy than a single larger unit. Secondly, depending upon arrangement, either static pressure or airflow may be increased while keeping the other parameter near constant.

When two fans work side by side, for example, airflow should double at free delivery. However, the higher the system impedance to flow, the lower the flow increase from the second fan. Hence, a parallel arrangement is recommended when the fans operate in low impedance near free delivery.

When one fan pushes air into an enclosure and another pulls air out, the fans are in series. Best results from using fans in series are in systems with high impedance.

In both series and parallel operation, especially with more than three fans, some areas of the combined performance curve are unstable and should be avoided. However, the instability is unpredictable because it results from several factors. For multifan operations, manufacturers recommend testing the setup under controlled conditions to assure satisfactory component cooling.



ELECTRICAL AND ELECTRONIC SYSTEMS

Write this number on the Reader Service Card to receive information from all advertisers making the listed products.

MOTORS
1206 Gearmotors
1207 Ac & dc,, fractional-horsepower
1208 Ac & dc, integral-horsepower
1209 Definite-purpose
1210 Linear
1211 Special-purpose
1212 Stepping
1213 Universal
1214 Protectors, current
1215 Protectors, voltage responsive
1216 Starters, electromagnetic
1217 Starters, manual
1218 Starters, solid-state

ELECTRICAL DRIVES
1219 Actuators, electromechanical
1220 Controllers & drive systems, stepper motor
1221 Controllers & drive systems, variable-speed, ac, eddy-current
1222 Controllers & drive systems, variable-speed dc
1223 Controllers, NC
1224 Controllers, power
1225 Controllers, programmable
1226 Controllers, temperature
1227 Converters, a/d and d/a
1228 Generators, ad & dc

INPUT/OUTPUT DEVICES
1229 Accelerometers
1230 Amplifiers
1231 Boards, logic
1232 Boards, matrix
1233 Boards, PC
1234 Boards, wire-wrap
1235 Capacitors
1236 Card cages
1237 Chassis
1238 Circuit breakers
1239 Counters
1240 CRTs
1241 Drivers
1242 Encoders
1243 Keyboards
1244 Lasers
1245 Load cells
1246 LVDTs
1247 Magnets
1248 Membranes
1249 Output devices
1250 Photocells
1251 Rectifiers
1252 Relays
1253 Relays, meter
1254 Relays, time delay
1255 Resistors
1256 Resolvers
1257 Sensors
1258 Sensors, position
1259 Sensors, pressure
1260 Sensors, temperature
1261 Servoamplifiers
1262 Servometers
1263 Servosystems
1264 Solenoids
1265 Steppers
1266 strain gages
1267 Suppressors, noise
1268 Switches, lever
1269 Switches, limit
1270 Switches, manual (DIP)
1271 Switches, photoelectric
1272 Switches, pressure or flow-operated
1273 Switches, proximity
1274 Switches, pushbutton
1275 Switches, rotary
1276 Switches, thermally operated
1277 Switches, toggle
1278 Tachometers
1279 Teletypewriters
1280 Timers
1281 Transducers
1282 Varistors
1283 Batteries
1284 Battery chargers
1285 Power supplies, modular
1286 Voltage regulators

INDICATORS & DISPLAYS
1287 LEDs
1288 Panel meters

INTERCONNECTIONS
1289 Blowers & fans
1290 Coils
1291 Circuit components
1292 Connectors
1293 Contacts
1294 Control panels
1295 Ducts
1296 Enclosures & housings
1297 Fiber optics
1298 Flexible circuitry
1299 Heaters & heating elements
1300 Heat shrinks
1301 Insulation, shielding
1302 Markers, wiring
1303 Plugs
1304 Receptacles
1305 Sockets
1306 Stamped circuits
1307 Terminals, wire

FLUID-POWER SYSTEMS

Advertisers

O Corporation 641
E Controls, Inc. 744-745
e Controls, Inc./Flairline 725
-Mite Devices, Incorporated 705
nerican Centrifugal, A Division of American Cast Iron Pipe Co. 657
tomatic Switch Company 697-700
rksdale Controls Division, IMO Industries Inc. 703
mba Manufacturing Company 753-756
sch, Inc. 686
rcle Seal Controls 705
ppard Instrument Laboratory, Inc. 691-694
lder Products Company 646
mmercial Intertech Corporation 760-762
schner Corporation 724
ectri-Flex Company 650
idine Incorporated 711-714
deral Brass Manufacturing Company, Inc. 653
sto Corporation 747-750
restone Industrial Products Company 721
ojet Corporation 685
uid Line Products, Inc. 646
lian Instrument Corporation 687
rman-Rupp Industries 685
aham-White Manufacturing Co. 685
lac Corporation 724
IO Industries, Inc. IFC,1
IO Industries Inc., Pump Division 674-675
e Company, The 705
gris Incorporated 649
arch Mfg. Co. Inc. 658
ico Incorporated 708
icro-Precision Operations Inc./ Subsidiary of Textron Inc. 735

A
Accumulators 682
Actuators, electrohydraulic 722
Actuators, rotary 736
Air versus electric 726
C
Compressors 659
Couplings 637
Cylinders 710
Cylinders, rodless 716
D
Dashpots 752
Dryers 631
F
Filters 624
Fittings, hose 637
Fittings, tube 640
Flow capacity 701
Flowmeters 650
Fluid motors 741
Fluids 617
G
Gages 655
H
Heat exchangers 648
Heat pipes 648
Hose 634
Hydraulic fluids 617
Hydrokinetic drives 751
Hydrostatic drives 742
Hydroviscous drives 751
I
Impellers 673
Intensifiers 682
L
Lubricators 634
M
Manifolds 644
Meters 655
Motors 741
Motors, axial-piston 741
Motors, axial-vane 742
Motors, gear 741
Motors, radial-piston 741
Motors, roller-gerotor 741
Motors, rotary-abutment 742
Motors, turbine 742
Motors, vane 742
P
Pipe 638
Pneumatics, proportional 707
Ports 638
Power units 681

Fluids, conductors, and conditioners

Power input and storage

Power modulation and control

Power actuators, motors, and shock absorbers

Milwaukee Cylinder 757
Mosier Industries, Inc. 737-740
NewAge Industries 653
Norgren 715
Oildyne, A Unit of Commercial Intertech Corporation 759
Oilgear Company, The 684
Parker Hannifin Corporation, Cylinder Division 723
Parker Hannifin Corporation, Fluid Connectors Group 619-622
Parker Hannifin Corporation, Hose Products Division 633
Parker Hannifin Corporation, Parflex Division 639
Parker Hannifin Corporation/Rotary Actuator Div. 743
Parker Hannifin, Tube fittings Division 643
Parker Schrader Bellows 6
Precision Tube Company, Inc. 653
Rexroth Corporation, The, Mobile Hydraulics Div. 709
Rexroth Worldwide Hydraulics 763
S.C. Hydraulics 687
Sheffer Corporation 727-734
Specken Drumag Company, Inc. 752
SUSPA, Inc. 717-720
Swagelok Company 627-630
Thomas Industries, Inc. 665-670
Tol-O-Matic, Inc. 724
Tuthill Pump Division, Tuthill 661
Uniform Tubes, Inc. 645
Union Carbide Chemicals & Plastics Specialty Chemical Division 635
Vickers, Inc. 688

Pressure regulators 704
Pump controls 679
Pumps, centrifugal 672
Pumps, circumferential-piston 671
Pumps, diaphragm 671
Pumps, flexible-vane 671
Pumps, fluid-transfer 664
Pumps, gear 677
Pumps, hydraulic 673
Pumps, lobed 671
Pumps, mixed-flow 672
Pumps, nutating 671
Pumps, peripheral 673
Pumps, peristaltic 671
Pumps, piston 679
Pumps, plunger 671
Pumps, vacuum 662
Pumps, vane 678
Pumps, volute/diffuser 672
Pumps and liquids 676

Q

Quick-action couplers 644

R

Reservoirs 647
Rotary actuators 736

S

Sensors, flow 650
Servovalves 707
Shock absorbers 751
Suction cups 662
System performance 683

T

Tubing 638

V

Vacuum pumps 662
Valves, ball 689
Valves, butterfly 690
Valves, cartridge 702
Valves, check 696
Valves, counterbalance 702
Valves, diverting 702
Valves, flow-control 695
Valves, fluid-transfer 689
Valves, gate 695
Valves, globe 689
Valves, needle 689
Valves, plug 689
Valves, pressure 702
Valves, proportional flow 706
Valves, relief 704
Valves, servo 707
Valves, slide 695
Valves, unloading 704

Fluids, conductors, and conditioners

A key element in fluid systems is the means of transmitting power from one location to another.

Constructing a hydraulic or pneumatic system involves the design or selection of numerous components, and determining how they will all interact. A point that is often overlooked is that the fluid, and the means of moving it from one location to another, are critical in any fluid-power system.

Because the functions of hydraulic fluid are rather basic — to transmit power efficiently and lubricate moving parts, with low maintenance — it is often taken for granted. But using the wrong fluid, or not maintaining it properly, means less than optimum performance, and can even destroy a system. Likewise, dirty air can foul compressors, jam valves, and ruin instrumentation.

In addition to fluids, the various lines that transmit fluid — tubing, hose, and connectors — and the components that keep the fluid in good working order — heat exchangers, filters, lubricators, and dryers — are essential ingredients to fluid-power systems.

Fluids

Petroleum-based fluids (hydrocarbons) traditionally have been the principal choice for hydraulic work. This choice remains popular where there is no danger of fire, no possibility of leakage into spoilable industrial products, no wide temperature variations, and no environmental considerations.

Fire protection, however, may dictate selection of a nonpetroleum fluid, especially when a broken hydraulic line could spray fluid into an ignition source. Work environment may suggest a nonhydrocarbon fluid where a hydrocarbon fluid could spoil food-related products or pollute a river.

Hydraulic fluid must also be evaluated for general compatibility with the system. Fluids are divided into five classifications for purposes of evaluation: premium antiwear, standard antiwear, rust and oxidation-inhibited nonantiwear, water-based, and phosphate esters. Also, standard antiwear and nonwear fluids are ranked according to their stability properties.

Premium antiwear fluids are recommended for systems using both piston and vane equipment. The fluids permit operation at full catalog rating with maximum life expectancy. Seal materials usually considered for these fluids are Buna-N or Viton-A; temperature range is 0 to 160°F.

Standard antiwear fluids are somewhat less stable than the premium fluids because they contain more additives. The fluids can be used with piston pumps, but speed must be limited to 1,800 rpm, temperature to 150°F, and pressure to 3,000 psi.

Vane equipment, on the other hand, can be used at maximum catalog rat-

CONTROLLING HYDRAULIC EQUIPMENT FIRES

Most hydraulic fluids are petroleum based with flash points above 300°F. They burn like any other oil, producing thick, black smoke. Leaks from hydraulic systems are particularly hazardous because the fluid sprays out from the crack or hole producing a fine mist. The mist is easily ignited by open flames, hot surfaces, cutting or welding operations, and molten metal. This pressurized fire quickly creates heat and smoke.

The first step in reducing risks is to develop a thorough housekeeping and preventative maintenance program so personnel can quickly identify and eliminate leaks or spills. In addition, a number of loss-control methods are available. The choices depend on a number of factors determined by a thorough risk analysis, such as: capacity of the hydraulic system, proximity of ignition sources, additional combustibles in the vicinity, value of the equipment and its importance to production, and available fire-protection equipment. Means of loss control include:

- Substitute less-hazardous hydraulic fluids in the system. These fluids are more difficult to ignite than petroleum-based oils and are less likely to be self-sustaining without a constant ignition source. Fluids that have been specifically tested for this purpose should be specified.

Several basic types of less-hazardous hydraulic fluids, such as synthetic and water based, are manufactured by a number of suppliers. A compatibility study is needed to match the fluid with the particular equipment and operating conditions.

- Install automatic heat-activated interlock devices to shut off the hydraulic system. These can consist of a fusible link, an individual heat detector, or other detection system. If a building sprinkler system is in place, water-flow alarms can be connected to the hydraulic system.

Well-designed and maintained automatic sprinkler systems are effective, time-proven means of safeguarding buildings and contents from fire. Reduced damage often results in faster cleanup and prompt restoration of equipment, allowing the plant to quickly resume production.

Periodic testing of the detection and interlock system is recommended. When only the sprinkler water-flow alarms are to be tested, a test switch avoids shutting down production equipment.

- Provide remotely located, well-identified means for emergency shutoff of the hydraulic pumping system in case of leakage or fire. Operators and emergency response team members should be aware of the location and operation of the shutoffs.

ings with maximum life expectancy. Recommended seal materials are Buna-N or Viton-A; temperature range is 0 to 160°F.

This class of fluids includes a less-stable group. The group contains fluids such as crankcase oils for gasoline and diesel engines. The same operating restrictions apply, but no stability criteria are given. Hence, systems using these fluids should have special controls for filtration, water contamination, foaming, and temperature.

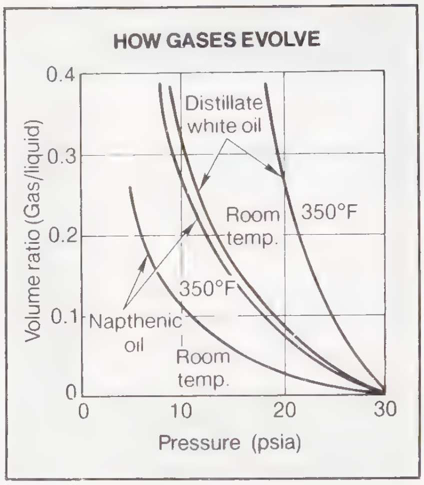
Nonantiwear, rust and oxidation-inhibited fluids are also divided into stable and less-stable types. The stable fluids, such as turbine oils, are the preferred fluids for piston equipment. The fluids permit operation at full catalog ratings with maximum life expectancy.

These fluids can be used with specially designed severe-duty vane equipment but at reduced ratings and life. Recommended seal materials are Buna-N or Viton-A; temperature limits are 0 to 160°F.

The less-stable class of these fluids includes tractor and transmission fluids. They are suitable for use in piston equipment at full catalog rating, but life expectancy is difficult to predict. Again, the fluids should be used only with specially designed vane equipment at reduced ratings and life expectancy.

Water-based fluids include invert emulsions and water glycols. Piston pumps operate satisfactorily on these fluids but have certain limitations. For instance, absolute inlet pressure should be about 25% higher than with petroleum-based fluids, and minimum inlet pressure is 13 psia. Because these fluids have lower lubricity, operating pressure is limited to about 3,500 psi, and speed to 1,800 rpm.

Only specially designed severe-duty vane pumps can be used with these fluids. Again, absolute inlet pressure should be 25% higher than with petroleum-based fluids, and minimum inlet pressure is 13 psia. Recommended seal materials are Buna-N or Viton-A. Operating temperature range is 50 to 120°F.


HOW GASES EVOLVE

Phosphate esters can be used with piston and vane equipment at full catalog ratings. However, absolute inlet pressure should be about 35% higher than for petroleum-based fluids. Viton-A seals are compatible with most phosphate esters; however, some of these fluids require EPR seals. Temperature range is 0 to 160°F.

Performance factors

The trade-offs necessary to choose a fluid involve a consideration of application requirements such as health, safety, and environmental effects, and fluid properties such as viscosity, stability, compressibility, gas solubility, and lubricity.

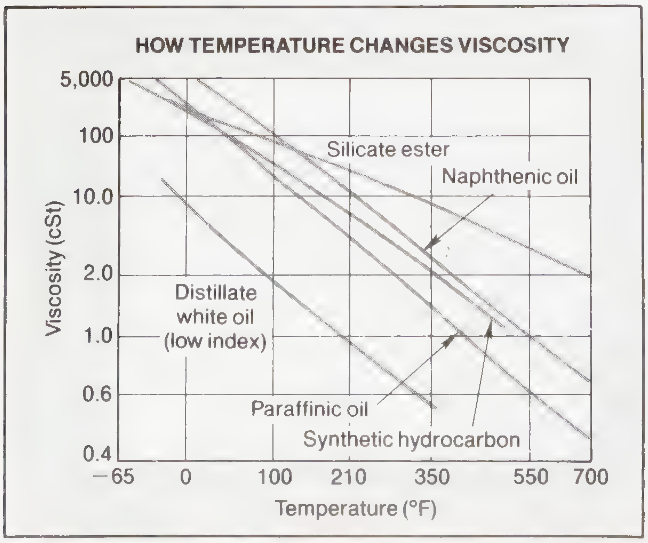
Viscosity measures how a fluid resists flow. It is the single most important property of a hydraulic fluid. A hydraulic fluid that is too viscous usually causes high-pressure drop, sluggish operation, low-mechanical efficiency, and high-power consumption. High-pressure, high-precision systems are particularly sensitive to viscosity at low temperatures. They can be penalized harshly by pump cavitation and sluggish response of critical actuators.

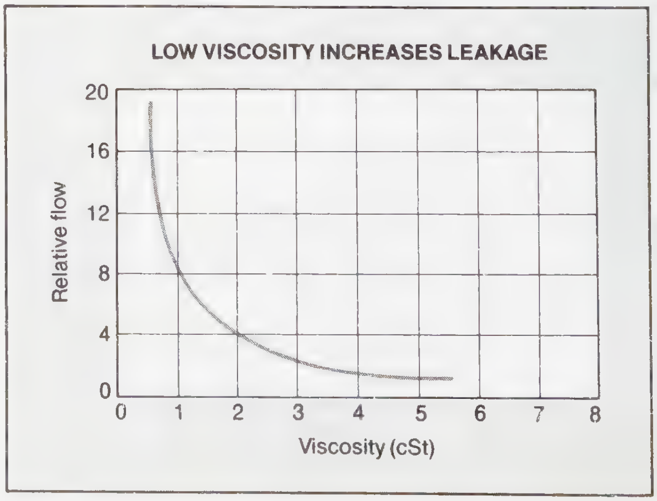
Low-viscosity fluids permit efficient low-drag operation, but tend to increase wear, reduce volumetric efficiency, and promote leakage. In theory, this leakage can be predicted on the basis of fluid viscosity and streamline flow through a known gap. But the clearance of some pump leakage paths depends on operating pressure and temperature, so leakage may show considerable deviation from the theoretical viscosity-flow curves.

Viscosity index measures how viscosity changes with temperature. Ideally, the fluid should have the same viscosity at very low temperatures as at high temperatures. In reality, this goal is unattainable. Fluids that come close to achieving the goal have high viscosity indexes; low indexes, on the other hand, indicate wide fluctuations of viscosity with temperature. Typical viscosity indexes for petroleum oils range from 90 to 105, and those for polyglycols from 160 to 200.

A high viscosity index is most important in applications subjected to a wide temperature range: mobile hydraulic systems used outdoors, industrial systems that are stopped and started during the winter in an unheated plant, and the like. These systems require a high viscosity-index fluid. An industrial system in a heated plant, on the other hand, could get by with a low viscosity-index fluid.

Some fluids have fairly high viscosity indexes to begin with. Others commonly have the viscosity index bolstered through the use of special additives. The additives are expensive, and tend to lose effectiveness under high


HOW TEMPERATURE CHANGES VISCOSITY


LOW VISCOSITY INCREASES LEAKAGE

Quick-reference guide to Parker Fluid Connectors ▶

Parker partnerships benefit customers worldwide

For more than 60 years Parker has led the fluid connector industry by anticipating needs and developing products and services that help our customers to be more competitive.

We work as a partner with our customers to optimize the performance of their hydraulic and pneumatic systems while reducing their purchasing and assembly costs. We also help increase their productivity with fluid connector training programs and advanced electronic communications such as EDI.

Our international network of distributors provides local inventories, engineering assistance, technical help and systems service. This network is supported by Parker's strategically-located manufacturing plants, extensive engineering, R&D and quality-assurance capabilities, advanced information systems, full-stocked service centers, and knowledgeable field-service people.

We want to be your partner, too.

The World Standard

Parker
Fluid Connectors

Parker Tube Fittings, Adapters

Ferulok Bite-type Flareless Fittings

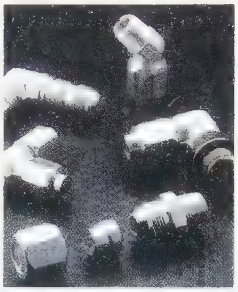
Specially designed for medium to heavy wall tubing, in high-vibration applications. Features a visible, metal-to-metal bite, for positive inspection during makeup. May be reassembled repeatedly and meet SAE J514, ASME, MIL-F-18866, and U.S. Army Ordnance standards. **Sizes:** -2 through -32. **Materials:** Steel, Stainless Steel (316), and Monel. **Details:** Catalog 4300.

Circle 430

Triple-Lok® 37° Flared Fittings

The original 3-piece fitting. Used with thin to medium wall tubing, and as a hose adapter. The design of Triple-Lok allows for a simple change of the sleeve for use with either inch or metric tubing. Available with NPTF, SAE Straight Thread, BSPP and Metric threads. More than 36 different shapes and configurations are standard. **Sizes:** -2 through -32. **Materials:** Brass, Steel, and Stainless Steel (316).
Details: Catalog 4300.

Circle 431



Seal-Lok™ O-Ring Face Seal Fittings

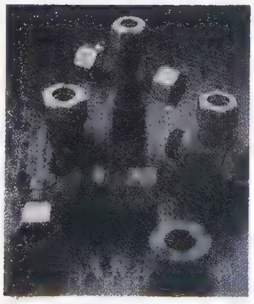
Positive sealing at rated pressures up to 6000 psi, in reusable connections for pneumatic and hydraulic tubing systems. The flat-faced body and sleeve allow drop-in installation of components. Seal-Lok's strong, forged bodies, longer rolled threads, and simple assembly by brazing, or flanging tube with Parflange 1030 machine, have made it the most popular new fitting since the invention of Triple-Lok. **Sizes:** -4 through -24. **Materials:** Cadmium-plated Steel and Stainless Steel. **Details:** Catalog 4300.

Circle 432

Tube Fabricating Equipment & Systems

In addition to its broad range of fittings, Parker also offers a score of hand and power tools and devices for all cutting, bending, flaring, flanging, pre-setting, counterboring, tapping, and clamping operations. For example, the Parflange 1030 offers an alternative to welding or brazing by flanging tubing for Seal-Lok ORFS connections. Can also flare tubing.
Details: Catalog 4300.

Circle 433

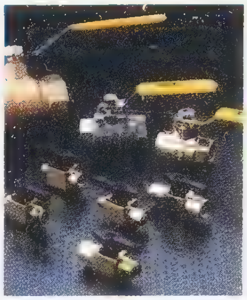


Metric Applications

Parker's proven designs are also available within the broadest range of metric products for diverse hydraulic and pneumatic applications. Metric sizes and standards are also available in Triple-Lok 37° flared fittings, JIS 30° fittings, EO bite-type fittings, pipe adapters and conversion fittings, hose adapters, metric tubing, and tube fabricating equiment. **Sizes:** 4 mm to 42 mm. **Details:** Catalog 4303.

Circle 434

Parker Brass Fittings & Valves



Ball & Plug Valves

Positive On/Off action for fuel line shutoff. and water service lines, anywhere total shu is essential. Ball valves available in bronze stainless steel, in FPT sizes 1/4″ through 2,″ pressures of 600 psi WOG, and 150 psi on/of saturated steam. A variety of styles availal including a padlocking ball valve to meet O regulations, and Mini Ball Valves in size 1/4 and 1/2″ for pressures to 300 PSI. Brass plu valves go from full open to full closed in a quick quarter-turn. In sizes 1/8,″ 1/4,″ 3/8,″ fo pressure to 250 psi. **Details:** Ball, Bulletin 35 Plug, Bulletin 3536.

Circle 435

Low Pressure Instant Fittings

Especially designed for low pressure pneumatic circuits, Parker Prestolok fittings allow instant assembly and disassembly of the tubing. These compact, one-piece brass fittings are for use with thermoplastic or soft metal tubing. Excellent sealing is effected with a nitrile O-ring, and no special tools are required. **Sizes:** Tube O.D. 1/8″ to 1/2″. **Threads:** 1/16″ to 1/2″ plus a 10x32 straight thread. Metric sizes also available. **Pressure:** Vacuum to 285 psi.
Details: Bulletin 3528.

Circle 436

Medium Pressure Brass Fittings

Parker Compress-Align® fittings require n preparation of the tubing. Pre-assembled fittings with captive sleeve are always orien for "right way only" installation. Heavy-du fitting aligns to seal even out-of-round tubi Interchangeable with standard compressio bodies, yet can be assembled faster than ei Flare or Standard Tapered Sleeve compress fittings. **Sizes:** Tube O.D. 1/8″ to 1″. **Threads:** to 1″. **Pressure:** 350 psi for 1″ O.D. tubing, to psi for 1/8″ O.D. tubing. **Details:** Bulletin 3524

Circle 437

Pneumatic Fittings

Parker Poly-Tite® fittings for plastic tubing are compact, brass compression devices with body, nut, and sleeve preassembled for speedy installation. Parker's exclusive acetal copolymer sleeve grips the tubing beyond its burst point. The result is reliable sealing in pneumatic instrumentation circuits and lubricant and cooling lines. **Sizes:** Tube O.D. 1/8″ to 1/2″. **Threads:** 1/16″ to 3/8″ plus a 10x32 straight thread. **Pressure:** 150 psi with thermoplastic tubing, 300 psi with soft metal tubing. **Details:** Bulletin 3525.

Circle 438

Air Brake Fittings

Available in two series to meet D.O.T. FMVS 571.106 and SAE J246 standards. Both are easily assembled, with no need for flaring special tools. The NTA® Series is used with SAE J844 Type 3A and 3B nylon tubing in a brake systems and cab air controls. The AB Series is used with copper tubing in air bra systems. **Sizes:** Tube O.D. 1/4″ to 3/4″. **Threa** 1/8″ to 3/4″. **Pressure:** AB Series — 400 psi, Series — 150 psi. **Details:** Bulletin 3501-E.

Circle 439

Parker FluidConnectors **Call toll-free 1 800 C-PARKER** *(1 800 272-7537) Dept. 122*

ker Pressure Hose, Fittings, Adapters

Parkrimp Assembly System

Select either portable or bench-mounted units to make Parker engineered permanent hose assemblies. It isn't necessary to remove the hose cover to install Parkrimp fittings that "bite the braid" for a metal-to-metal grip. There are no guages to set, and color-coded, pre-linked dies simplify operation. **Capacity:** 1/4″ through 2″ I.D., including SAE 100R13 6 spiral hose. **Details:** Catalog 4480.

Circle 440

kive Crimp Fittings

with Parker's field-crimp system, it is not
sary to skive the hose to use these one-
fittings. Available in steel and stainless
these fittings feature teeth that grip the
ose reinforcement for maximum
ity. Available from 1/4″ to 2″ in all
ar end configurations, standard and
c. **Details:** Catalog 4480.

Circle 441

No-Skive Reusable Fittings

Why spend time removing the protective cover on the hose to install the fittings? Parker's No-Skive field-attachable fittings are installed without skiving, yet their unique design enables the fitting to grip the wire hose reinforcement for maximum performance, with minimum chance of corrosion. Parker offers a wide variety of reusable hose fittings, from 3/16″ I.D. to 2″ I.D. Parker 20 Series reusable fittings are available in brass and steel for wide variety of SAE 100R5 type hose constructions in sizes ranging from 3/16″ I.D. to 2-3/8″ I.D. **Details:** Catalog 4400.

Circle 442

Pressure Push-Lok Systems

ole for shop air systems and most
trial and automotive applications. Parker
Lok hose and fittings assure positive
ections without the use of clamps, wires,
or bands. Available in 6 colors, hose sizes
4″ through 3/4″ for working pressures to
si. Specific types available for flame-
ant, heat-resistant, and silicon-free
cations. More than 20 different standard
etric fitting styles are available in brass,
and stainless. **Details:** Catalog 4400

Circle 443

Adapters & Accessories

Parker offers a wide range of adapters, including pipe, JIC and Seal-Lok, and adapters that swivel under pressure. Accessories include Partek protective nylon sleeving, spring and armor guards for extending hose life. **Details:** Partek Bulletin 4490-B5, Catalog 4400.

Circle 444

Parker Quick Couplings

Pneumatic Exhaust-type Coupler

Advanced E-z-Mate design uses a sliding sleeve as an integral system valve. Lets you control the air supply and make all connections at zero pressure. No matter what size coupling, the connect force is only 8 lbs. These steel couplers are rated to 300 psi. **Sizes:** 1/4″, 3/8″, 1/2″ and 3/4″ with female and male pipe threads and hose barb. Accepts Industrial Interchange nipples. **Details:** Catalog 3806.

Circle 445

Pneumatic Sleeve-type & Push-to-connect Couplings

Quick connect disconnect for more productivity and less downtime for air-operated equipment. Special features include exclusive tubular valve for minimum pressure drop, compact design, and protective collar to minimize accidental disconnect. Rated to 300 psi. Parker 20 and 30 Series couplings accept Industrial Interchange (MIL-C-4109) nipples. **Sleeve type:** brass. **Push type:** solid brass. **Sizes:** 1/4″, 3/8″, 1/2″ and 3/4″ with female and male pipe threads and hose barb. For gas, limited vacuum, and low pressure fluids. **Details:** Catalog 3806.

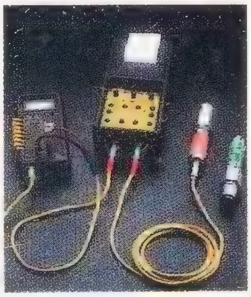
Circle 446

Double Shut-off & Straight-thru Couplings

Industry's broadest choice of medium-to-high pressure hydraulic couplers and nipples. Ball locking and thread-to-connect designs, poppet or ball valves, and a wide selection of barstock materials and fittings. Special purpose couplings include Bruning Hydraulic flush-face (HTMA) and Non-Spill couplings; connect-under-pressure couplings; and the popular Moldmate Series for mold coolant line connections. **Materials:** Steel, Brass, and Stainless Steel (303 and 316). **Sizes: 1/8″ through 1/2″. Ratings:** from 800 to 10,000 psi. For chemicals, water, steam and gas. **Details:** Catalog 3807. **Circle 447**

Portable Diagnostic Equipment and Diagnostic Quick-Action Couplings

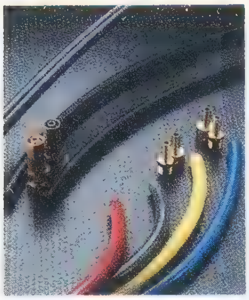
Senso Control system helps you install, analyze, maintain, and trouble-shoot hydraulic equipment. Just push a button to obtain pressures, temperatures, and differentials. So sensitive it registers pressure spikes; often an early warning of system breakdown. And, for the record, it gives you a hard copy of its reliable data. Couplings have self-cocking knurled sleeve making them a snap to use in even the tightest spots. Nipples mount in the fluid line for instant measuring access. **Details:** Catalog 3808. **Circle 448**



Check Valves

Specifically designed to assure fluid flows in one direction only, Parker's Bruning hydraulic check valves feature exclusive double seal and cushioned poppet for years of trouble-free operation. Available in regular and cartridge-type inline units and split-flange mount units. Wide range of sizes, pressure ratings, flow capacities and crack pressures (nearly 5,000 configurations). **Sizes:** 1/4″ to 2″ **Flows:** 0 to 350 GPM **Pressures:** 0 to 3000 psi. **Details:** Catalog 3809.

Circle 449



Hydraulic & Pneumatic Hose

A full matrix of thermoplastic tubing and reinforced hose products in a wide range of materials to match your specific need in low, medium and high pressure pneumatic and hydraulic uses. Meet or exceed SAE 100R7 and SAE 100R8. The Parflex® line also includes many special-purpose hoses such as Wire reinforced and Non-conductive. Choose from a full line of metric and standard swage or crimp-type permanent fittings or reusuables in steel, stainless or brass. **Sizes:** 3/16″ thru 1-1/8″ I.D. Ratings from 250 thru 5,000 psi.
Details: Catalog 4660. **Circle 450**

Insulated, Bundled & Traced Tubing

For service indoors or out, above ground or below, here's all the pneumatic instrumentation lines you need. Custom designed and built to your specs in the materials your media demand: copper, aluminum, stainless, nylon, PVC, FRPT, HDPE and more. Use Parker pre-insulated TEMPTUBE® to protect process lines from freezing or setting-up. Choose Parker TEMPTRACE® single or bundled process tubing with optional steam or electric tracing to maintain process temperatures or for stack gas sample lines.
Details: Bulletin 4200M **Circle 451**

Extruded Elastomeric Special Purpose Tubing

Your choice of 8 specific series and 5 different materials within the Parflex® line. From instrument grade to flame resistant, food contact to pneumatic control, you'll find it in our Polyethylene, Nylon, Polypropylene and Clear Vinyl series. For example, excellent "memory" is key to Fast-Stor® self-retracting coils for pneumatic tool lines. Heavy-duty brass fittings have built-in insert tube supports in all standard SAE sizes. In Nylon and non-marring Urethane. **Details:** Catalog 3600.

Circle 452

Thermoplastic Fittings

Industry's most complete line for use with thermoplastic tubing. New **Tru-Seal™** fittings are the first reusable, all-plastic, metal-free push-in fittings that are easily assembled *without wrenches or special tools.* Tru-Seal fittings feature a polymer grab ring that eliminates possible metal corrosion and prevents tube damage during connection and disconnection. **Par-Barb** fittings use a specially engineered four-barb design in conjunction with a hose clamp, for maximum grip and sealing power. Used where pressures do not exceed 125 psi, Par-Barb fittings meet F.D.A. and N.S.F. specs for food contact and potable water. **Details:** Catalog 3600.

Circle 453

TFE Hose & Fittings

Parker TFE hose withstands heat, cold, shock, flexing and corrosive atmospheres that ruin other hoses. Available with stainless steel or bronze wire braid outer cover for working pressures from 175 to 3,000 psi. Wide range of permanent and reusable fittings.
Details: Bulletin 4690

Circle 454

Parker.
The One-Source you can depend on for Total Fluid System Response-Ability Worldwide.

Complete Selection
Offering the most complete lines of hydraulic and pneumatic components available from a single manufacturer, Parker provides machinery designers, builders and users with a balanced selection of performance-matched components for total systems engineering.

Worldwide Availability
Parker's international distribution network is one of the strongest in the industry. This worldwide network is supported by strategically-located manufacturing plants, fully-stocked service centers and distribution warehouses manned by trained applications and field service people.

Complete Systems Capability
Your local authorized Parker distributor is staffed with trained specialists to provide engineering assistance, technical help and full-system service.

Wherever in the world machinery is designed, manufactured or used, Parker is there with components, complete systems, and qualified people—for a totally integrated and professional fluid power service.

Call us toll-free
1 800 C-PARKER *(1 800 272-7537)* *Dept. 1*
Parker Hannifin Corporation
Fluid Connectors Group
17325 Euclid Avenue
Cleveland, Ohio 44112-1290

Catalog 3400 1/92
1991 Parker Hannifin Corporation

shear rates during long service. But if monitored carefully, oils with viscosity-index additives perform well in industrial service.

Pour point is the lowest temperature at which oil flows when chilled under specified test conditions. It is important if the system is regularly exposed to low ambient temperatures, but relatively insignificant if the system is to be used inside a heated plant. Pour point of the oil should be about 20°F below the lowest expected temperature.

Compressibility is the degree to which a fluid undergoes a reduction in volume under pressure. As a rule of thumb, compressibility is about 0.5% for each 1,000-psi pressure increase up to 4,000 psi.

Compressibility, or bulk modulus, has its greatest effect on performance in servo applications. It determines system static rigidity and strongly influences system gain, or amplification. Because compressibility increases with pressure and temperature, it is important to systems with high-pressure pumps and motors.

In positive-displacement pumps, the effect of bulk modulus shows up as a loss in volume. This loss represents a power loss, because few actuators recover the compressive energy in the fluid.

Stability is the most important property for longevity of service. Ideally, the properties of hydraulic fluids should not change with use. But certain factors can adversely affect fluid performance.

Mechanical stress from flow and cavitation can shear polymer chains, breaking down viscosity improvers and reducing viscosity. Oxidation and hydrolysis tend to cause chemical changes and the formation of volatile components, insoluble materials, and corrosive products.

Heat can also destroy a fluid, and the higher the temperature, the shorter the life of the fluid. A hydraulic system should operate below 250°F, ideally between 100 and 150°F. An old rule of thumb states that for every 10°C or 18°F of temperature rise, the rate of oxidation doubles. Thus, a fluid used at 110°C has about half the life as at 100°C.

When a system operates at high temperatures, additives must be selected carefully. Some additives, while doing an excellent job at normal operating temperatures, have limited thermal stability. Chemical breakdown occurs, and the additive, instead of being a benefit, begins to harm the system.

Contaminant particle sizes that can be tolerated in a hydraulic system are the same whether a fluid is synthetic or petroleum based, emphasizing the need and importance of good filtration and diligent maintenance practices. Insoluble contaminants can be hard particles or sludges and gums. Hard particles can accelerate wear of closely mated moving parts such as pumps, motors, and valves. Sludges and gums can slow valve action, particularly if these agents harden into varnish films. Furthermore, silting caused by all forms of solid materials will slow servovalves. Excessive production of these solids can clog even large filters.

Corrosive agents usually form because of thermal or oxidative decomposition, or in the course of hydrolysis. These corrosives are usually acidic, but not all acidic materials are corrosive. In most instances, corrosion increases leakage by opening up tolerances of close-fitting parts. But where pitting occurs, there can be substantial localized loss of strength.

Lubricating ability is an important quality factor in hydraulic fluids, since the fluid must lubricate moving parts of the system to minimize wear. Most petroleum fluids satisfy the lubrication requirement in pumps, motors, and valves. However, certain types of hydraulic pumps and motors place severe load-carrying requirements on the oil; fluids for these applications should be fortified by antiwear additives. Where boundary lubrication conditions prevail, glycol-based fluids are satisfactory. They are stable in hydraulic service and their viscosities are unaffected by high rates of shear. They also resist the formation of varnish and sludge, and resist viscosity increases caused by soluble oxidation products.

Volatility is rarely the cause of pump cavitation. The reason: Vapor pressures of most hydraulic fluids are too low to cause boiling at the pump inlet. In most systems, the cause of cavitation is dissolved air.

The amount of gas dissolved in hydraulic fluid depends on the partial pressure of the gas in contact with the fluid. Although gas solubility increases slightly with temperature, pressure has a far greater effect.

Volumes shown in the accompanying graph were calculated under the assumption that fluids were saturated with nitrogen at 30 psia, that gas phase follows the gas laws, that gas evolving from solution is saturated with vapor of the liquid, and that equilibrium is established. For pumps with short inlet lines and laminar flow within the line, the actual volume evolved may be less, because the fluid does not reach equilibrium. However, turbulence agitates the fluid and speeds gas evolution.

To prevent cavitation, some reservoirs — particularly in aircraft systems — are pressurized. Systems pressurized by pumping air into the reservoir require higher reservoir and inlet pressure than those pressurized mechanically. The reason is that air pressurization automatically dissolves more gas in the fluid.

Aeration and foaming resistance is another important indicator of fluid quality. Fluid in a hydraulic system always contains air as entrained bubbles, as well as in solution. The entrained air tends to increase compressibility of the fluid, making the system elastic, noisy, and erratic. Compression of this air generates heat and can increase oxidation.

Volumetric efficiency of the pump is reduced because air bubbles in the oil on the inlet side expand as the oil enters the pump. When the bubbles collapse on the discharge side, they can produce damage similar to cavitation erosion. Many high-quality fluids contain antifoaming additives to release air readily.

Corrosion prevention capabilities of an oil are important because moisture is always present in hydraulic systems. Since most components have ferrous metal surfaces, subject to rusting, corrosion prevention is essential. It is normally provided through an additive called a rust inhibitor in the oil. The inhibitor plates out on the metal surfaces to form a protective film.

Materials compatibility enters the picture as a final arbiter of which seals and components can be used with a certain fluid. For example, natural rubber is not oil resistant and should not be used in hydraulic systems using petroleum oils.

Synthetic rubbers vary widely in their behavior when exposed to different fluids. In contact with a given fluid, some are unaffected, but others swell, shrink, or otherwise deteriorate.

Most seals in contact with oil are made from nitrile rubbers. Other materials suitable for oil systems include Neoprene, silicones, and fluorocarbon rubbers. Most tubing and fitting manufacturers present extensive tables of materials compatible with their product specifications.

Some antirust additives used in hydraulic systems may attack zinc. Therefore, galvanized and other zinc-coated surfaces should be avoided. Zinc is also objectionable in a hydraulic system because products of oil oxidation can react with it to form metallic soaps.

Other materials susceptible to corrosion are magnesium-based alloys and lead. Magnesium alloys generally suffer heavy corrosion when water is present. Lead is attacked by products of oxidation.

Copper should also be avoided in hydraulic systems, but for a different reason. It is an effective catalyst in promoting oxidation of all types of oils. So heat exchangers should be of steel, rather than copper or brass.

Hydraulic and pneumatic filters

The typical hydraulic system is cleaned by a single filter in the circuit. Often this filter is located on the inlet line in front of the pump, to protect the pump and downstream components; so used, it is occasionally called a "suction filter" or "suction strainer." Many pump manufacturers object to this filter location, claiming that it "starves" the pump inlet, so the filter may be located at other points in the circuit, such as on the return line, in a pressure line, or on a bypass line.

Filtration for pneumatic systems is handled quite differently. In most industrial pneumatics, compressed air is supplied from a single compressor to a large number of operating systems, as a plant resource, much like light or electricity. Individual filters are used on the separate systems — sometimes more than one filter per system. Often the filters are found in conjunction with regulators and sometimes lubricators comprising a filter-regulator-lubricator (frl) for the system.

Filters are rated on the ability to retain contaminants of certain size levels.

Beta rating: Beta filtration rating is a ratio. It compares the number of particles of a given size or greater in the fluid upstream of the filter, to the number of particles of the same size or greater in the downstream fluid.

The ratio is expressed by

$$\beta_x = N_u / N_d$$

where β_x = Beta filtration rating for particles larger than x microns, N_u = number of particles larger than x microns upstream of the filter, and N_d = number of particles larger than x microns downstream of the filter.

The Beta filtration rating can also be converted into an efficiency rating, E_x. Efficiency rating is expressed as a percentage of the filter medium's ability to remove particles larger than x microns:

$$E_x = \frac{\beta - 1}{\beta} \times 100\%$$

A filter with a reported rating of $\beta_3 > 100$ removes a minimum of 99% of all particles larger than 3 μm. Similarly, a filter rated at $\beta_{10} > 20$ captures a minimum of 95% of all particles larger than 10 μm. Clearly, the element rated at $\beta_3 > 100$ removes many more small particles than the element rated at $\beta_{10} > 20$, especially in the 3 to 10-μm range.

The Beta filtration rating is a widely used rating system for filter-media performance. It is an attempt to standardize a rating system within the industry and to give both users and manufacturers an accurate means of filter comparison.

ISO 4406: ISO 4406 is a hydraulic cleanliness rating system based on the number of particles larger than 5 and 15 μm in a 1-ml fluid sample. A standardized chart is then referenced to convert the particle counts into the ISO 4406 rating format. For example, a 1-ml sample containing 140 5-μm particles (ISO 4406 range number = 14) and 28 15-μm particles (ISO 4406 range number = 12) has an ISO 4406 cleanliness rating of 14/12.

ISO 4406 range numbers

Number of particles per ml		ISO 4406 range number
greater than	up to	
80,000	160,000	24
40,000	80,000	23
20,000	40,000	22
10,000	20,000	21
5,000	10,000	20
2,500	5,000	19
1,300	2,500	18
640	1,300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7
0.32	0.64	6
0.16	0.32	5
0.08	0.16	4
0.04	0.08	3
0.02	0.04	2
0.01	0.02	1

ISO 4406 is an internationally recognized standard for expressing the level of particulate contamination in hydraulic fluid, and for specifying required cleanliness levels for hydraulic components and systems. The widely accepted system provides a consistent and meaningful vehicle for dialog between manufacturers and users.

Pall cleanliness code: Some users and manufacturers of hydraulic systems have complained about a potential problem with interpreting portions of ISO 4406. According to Pall Industrial Hydraulics Corp., fluid samples with a high silt content (0 to 3 μm) can be reported as clean according to ISO 4406. To differentiate between usable fluids with a clean rating and silt-loaded fluids with the same rating, Pall has proposed a cleanliness code with a three-number format. Rather than invent a new rating system, Pall suggests to simply expand ISO 4406 to include a third range number that considers the contamination level of particles larger than 2 μm.

Absolute rating: Absolute filtration rating specifies the diameter of the largest hard, spherical particle that passes through a filter under controlled conditions. The rating is also an indication of the largest opening through a filter.

To determine absolute rating, the filter is installed in a test system. Test fluid is first circulated through a cleanup filter until fluid sampling indicates no more than 0.0004 *g* of contamination per 100 ml. A specific amount of artificial contaminant is mixed with the clean test fluid, thoroughly agitated, and then a measured quantity of the mixture is passed through the test filter and collected in a container. The fluid is then passed through a very fine membrane filter with a typical pore size of 0.45 μm. The membrane filter is then examined under high magnification to determine the diameter of the largest particle captured. The diameter of the particle, expressed in microns, is the absolute filtration rating of the tested filter element.

Nominal rating: Nominal filtration rating is an arbitrary value determined by the filter manufacturer. The rating system refers more to the types and sizes of holes in the filter medium than actual filter performance.

Nominal filter ratings have many limitations. First, they do not present a clear indication of the largest-size particle that can pass through a filter. Second, it is a nonstandard system that lacks consistency from one manufacturer to another. As can be expected, nominal filtration ratings can lead to problems in the field. In fact, perhaps the most common filter-related application error is selecting an element based on nominal rating. This typically leads to contaminated systems and accelerated component failure. Due to these factors, nominal ratings have lost favor to the more sophisticated Beta filtration rating system.

The life of a hydraulic or pneumatic component depends on the type, amount, and size of contaminant particles passing through it. Since each component has a different resistance to contamination, the filtration level must be matched to the system's most sensitive component.

To ensure maximum reliability, β ratio could be specified to maintain contaminant levels far below those actually required. But this approach increases both initial and maintenance costs; therefore, filter rating and size must be carefully matched to system needs to produce the most economical system.

Another important factor controlling system reliability is filter location. Placement of the filter in the suction, pressure, return, or bypass line could require different filter specifications because system parameters such as pump flow rate, reservoir size, reservoir contaminant level, contaminant ingestion rate, and flow rate can change with filter location. All these parameters combine to control the required filter β ratio.

A suction-line filter removes contaminants before they enter the pump. Since the reservoir collects all generated and ingested contaminants, it can be considered as the contaminant ingestion point for the circuit.

A pressure-line filter removes contaminant either between the pump and the other components or between any of the components. The ingestion point is either between the pump and filter or at the reservoir. Similarly, with a return-line filter, the ingestion point can be either between the work components and filter or at the reservoir.

A bypass circuit allows a large portion of the total pump flow to bypass the filter. In such a circuit, the filter handles only the amount of flow necessary to maintain the contamination level required by the system components. This lower flow specification allows the use of a smaller, less-costly filter, but can still provide maximum component life. In the bypass circuit, the ingestion point can be after the work components but before the bypass line or at the reservoir.

Filter cost generally increases with increasing size and increasing β ratio, with size having more effect. Since suction and pressure-line filters must handle higher-pressure flows, these installations may require larger, more-expensive filters. Return-line and bypass filters, on the other hand, operate at lower pressure and, thus, are usually less expensive.

Pneumatic filters also require careful selection, but the process is not quite as involved. The reasons for this are simple: Because pneumatic devices operate at lower pressures than hydraulic components, tolerances in them are typically much larger. Accordingly, the opportunity for abrasive and silt-induced wear is considerably reduced. Also, air does not entrain and carry along particles at the same density as hydraulic fluid, so the task of filtering a pneumatic system is reduced.

The situation is much more critical if the air is to be used with fluid logic components that are sensitive to the presence of oil aerosols. For these jobs, most experts recommend various types

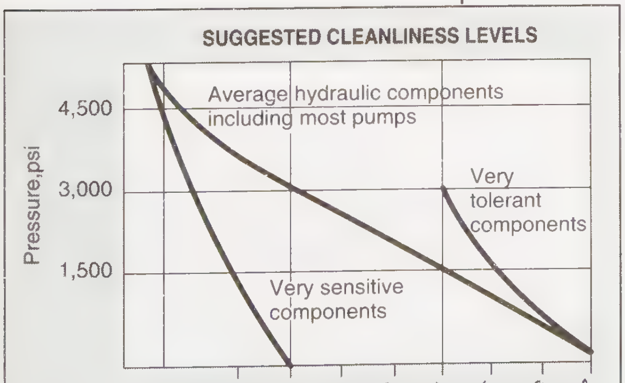
FILTER SELECTION

At first glance, rating systems may appear to be confusing. The reality, however, is that filtration systems can be designed in a straightforward manner. First, determine the cleanliness requirements of the hydraulic system in a format according to ISO 4406. Then allow a filter supplier to determine the appropriate filtration hardware. Letting the filter supplier select the filter is important because there is no reliable correlation between hydraulic system cleanliness requirements (ISO 4406) and hydraulic filter performance (Beta filtration ratings). Until filter manufacturers publish correlation data between ISO 4406 and Beta, the responsibility of selecting filtration hardware should rest on their shoulders.

CLEANLINESS REQUIREMENTS

Filter performance-rating systems can be critical to optimum hydraulic-system operation. One important point that cannot be overlooked, though, is the cleanliness requirements for hydraulic systems. Obviously, all applications are not the same and all systems do not have the same demands. Factors such as contamination sensitivity, operating pressure, and flow rate have an influence on how clean a system must be.

For some general-purpose hydraulic systems, cleanliness requirements can be assessed according to the accompanying graph. Realistically, however, the graph can only be regarded as a rule-of-thumb. With many high-performance hydraulic systems, downtime cost and liability risk posed by system failures tend to require more detailed analyses.



One comprehensive procedure for determining cleanliness requirements is the Contaminant Life Index (CLI) developed by James C. Fitch.

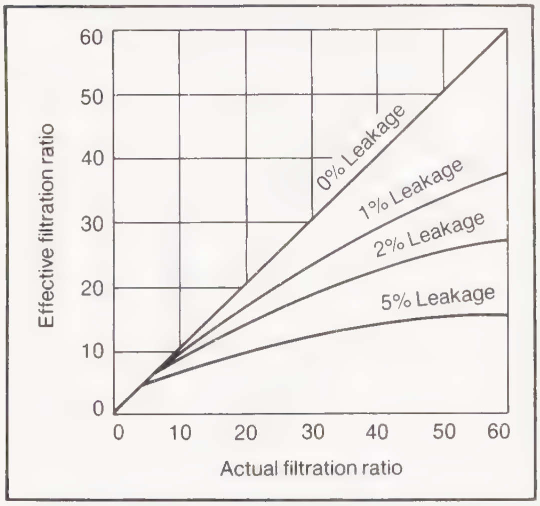
As a starting point, the CLI establishes the contaminant sensitivity of a system in terms of its design features, operating conditions, and application. The index identifies many factors that influence cleanliness requirements, such as system pressure, type of fluid, the number of servovalves, and maximum flow rate, and weighs the relative importance of each. The method also takes into consideration the cost of contamination control, because filtration costs should not exceed the monetary benefits that filters provide. In the end, individual scores are totaled and compared to a correlation chart. From that chart, the final score, or index, is translated into ISO 4406 range numbers.

The CLI presents a technique that can be applied to most hydraulic systems. Though perhaps not perfect, it goes a long way toward the goal of a user-friendly method for a comprehensive analysis of hydraulic system cleanliness requirements.

RELATING MULTIPASS TEST TO ACTUAL PERFORMANCE

The multipass filter test (ANSI B93.31) is widely accepted for rating hydraulic filter performance. In particular, it is a good way to compare one filter to another. However, applying the ratings directly to a field situation is generally not wise. In most cases, real-life performance will not match laboratory test results.

One reason is the significant difference between the type and size of contaminants found in the multipass test and those found in actual systems. The multipass test uses AC test dust, a carefully controlled mixture of silica particles, ranging from 1 to 100 μm in size. In real life, the size distribution of contaminant is seldom similar to that of the test dust.



This means that filters having a specific filtration ratio under test may have a considerably higher ratio if the actual system contains a higher percentage of large particles than found in AC test dust. Simply stated, large particles are more likely to be captured in a filter than are small particles. Likewise, the ratio will be lower if the system contains mostly fine particles.

Another built-in shortcoming of the multipass test is that it is run at steady, noncylic flow rates. In the real world, cyclic flow is fairly common, due to variable-volume pumps or flow multiplication in actuators. Cyclic flow significantly reduces the effective efficiency of some filters. Basing filter selection solely on multipass test data could result in a filter that tests well in the laboratory, but fails when subjected to field conditions.

Another difference between test and actual conditions is bypass leakage. In the multipass test, no fluid is permitted to bypass the filter element. But 1 to 2% bypass leakage is a real possibility in many filter assemblies used in the field. Almost all filter housings contain some type of relief valve, and the element must be sealed in the housing. Both the bypass valve and the element/housing seal interface offer a real potential for bypass leakage.

The effect of bypass leakage on filtration ratio is dramatic, particularly in high-efficiency filters. The chart shows that the maximum filtration ratio for any filter assembly with 1% bypass is 100; with 2% bypass it could not exceed 50; and 5% bypass leakage would produce a maximum ratio of 20, regardless of the filter's multipass test rating.

From a designer's standpoint, a well-designed filter housing — one that effectively prevents bypass leakage under normal operating conditions — is more important than extremely high filtration ratios.

---

of coalescing filters. A typical coalescing filter passes through four levels of filter media, including a foamlike core, a special filter which may be fiberglass, a perforated shroud of steel, and a foam cover. Such a filter is claimed to coalesce over 99% of all oil and water aerosols, in addition to removing solid particles of 0.01 μm or larger. In systems with significant quantities of oil, condensate, or scale, a roughing filter extends the life of the coalescing filter.

Most pneumatic filters of up to 2-in. pipe size are made with a removable reservoir bowl. This feature permits maintenance of the filter without the need to break pipe connections. When the filter is depressurized, the bowl can be removed and cleaned, and the filter element can be replaced or cleaned as required. Filter bowls are available in transparent plastic and in metal. Bowl guards to fit over transparent bowls are available from most manufacturers; metal bowls are considered safer in severe environments. To provide visibility, metal bowls may include a sight glass.

All compressed air filters must be drained. Manual drains on small filters are usually simple petcocks at the bottom of the bowl; large filters are drained manually through a valve. Automatic drains are available for all sizes of filters to simplify maintenance.

Normally, the choice of a specific element is pretty easy. If simple chip control is required of a filter, the element can usually be a straight wire mesh or screen with relatively coarse holes. Such screens are often rated by mesh size or by pore size.

For chip control, a so-called 100-mesh screen provides absolute filtration of about 220 μm. A 200-mesh screen filters to 105 μm, a sintered-woven wire mesh may filter to as fine as 25 μm absolute, and resin-impregnated paper (disposable) will filter to around 30 μm absolute.

If silt control is the required function, special filters that are capable of 1 to 5-μm absolute filtration are necessary. Unlike the various metal chip-control filters, which are cleanable, the silt-control filters are nearly always made of a material that cannot be cleaned; they must be disposed of when they become filled.

Whichever filter element is used, its collapse pressure should be considerably higher than the pressure flow through the filter bypass valve at peak surge. A generous margin of safety here insures against filter collapse.

If the system requires that no dirt be allowed to pass through the bypass valve, experts recommend a filter without bypass; such a filter element must have a collapse pressure equal to the operating system pressure.

All materials used in the filter element must be compatible with the hydraulic fluid to be used over the entire temperature range expected in service.

Because most hydraulic systems fluctuate pressure and flow, filter elements used in them must be designed to withstand resultant cyclic stress. Filter elements designed for long life under fatigue conditions are available and required in most hydraulic systems.

Filter elements chosen must have adequate on-stream life. Element life is measured by manufacturers with a dirt-capacity test, in which the weight of an artificial contaminant added to the filter to attain a preselected differential pressure is measured. Normally, filter manufacturers can recommend a filter with adequate life for a particular application. Because service conditions may vary, this service life is seldom guaranteed; for critical applications, it may be necessary to "derate" the filter to ensure that the filters do not fill or

Quality is a commitment for all time.

Along with the dramatic changes our technologies have produced during this century, I have observed a fundamental that never changes: quality products and progress go hand-in-hand.

Quality products support the ingenuity of the thinkers and the expertise of the doers. Quality products provide extra values that keep the cost of progress under control.

Commitment to quality has guided The SWAGELOK Companies since we began business in 1947. That is another fundamental that never changes. Quality is a commitment for all time.

Fred Lennon

Fred A. Lennon
Chairman,
The SWAGELOK Companies
SWAGELOK Co., Solon, Ohio 44139
SWAGELOK Canada Ltd., Ontario

© 1991 Swagelok Co., all rights reserved FS-2-097

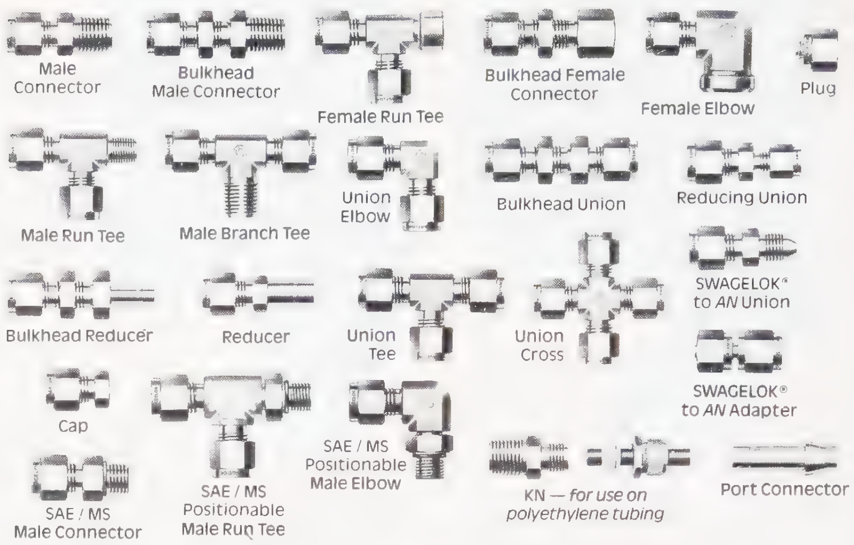
the SWAGELOK companies

Circle 455

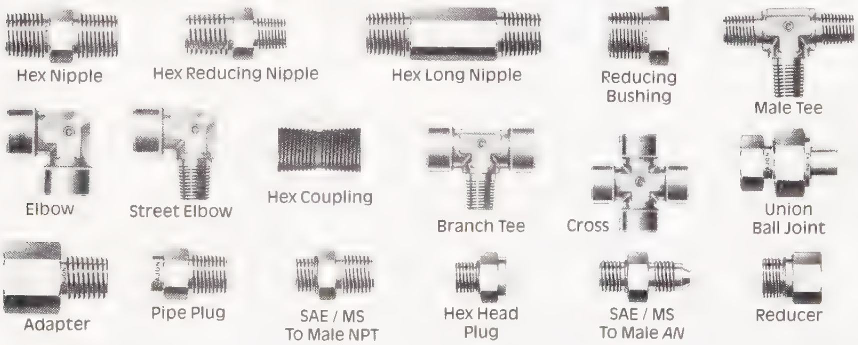
Build Leak-Tight Performance into your Designs

...with Valves and Fittings from the SWAGELOK® companies

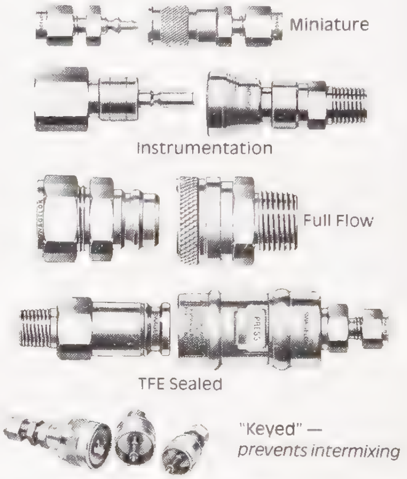
SWAGELOK® Tube Fittings 1/16″–2″, 2mm–25mm • all machineable metals and plastics



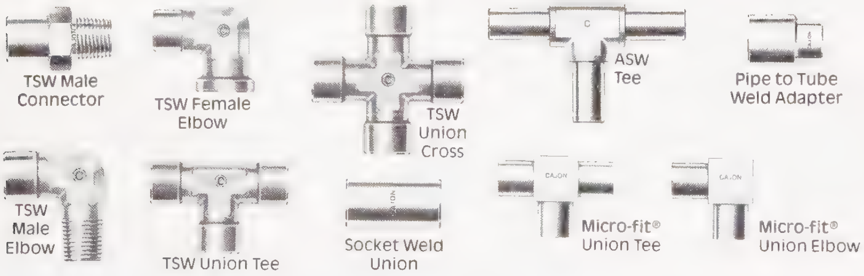
Pipe Fittings 1/16″–1″ • wide range of materials • to 11,000 PSI



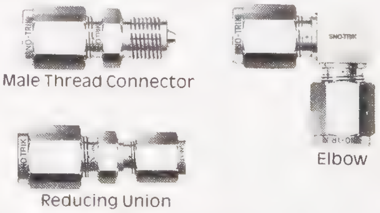
Quick-Connects 1/16″–1″ • 316SS, brass • single-end or double-end shut-off • to 400°F and 6,000 PSI



Weld Fittings 1/8″–1″ • 316SS • to 11,800 PSI

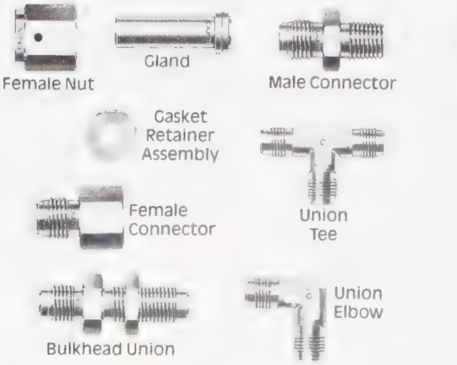


High Pressure Fittings 1/4″–9/16″ • 316SS • to 60,000 PSI

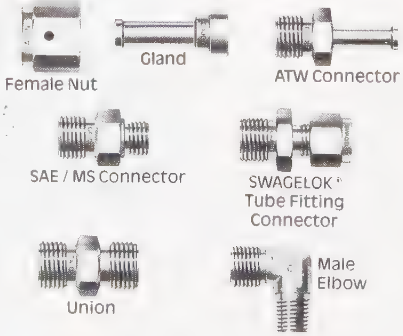


Face Seal Fittings

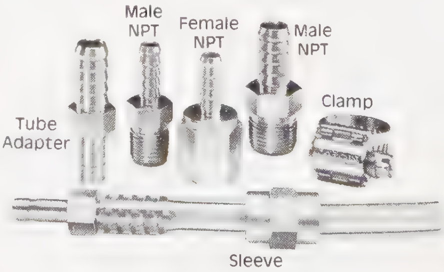
VCR® metal gasket sealed – 1/16″–1″ • 316SS • to 1000°F and 11,000 PSI



VCO® O-Ring sealed – 1/8″–1″ • 316SS and brass • to 450°F and 10,000 PSI



Hose Connectors 1/8″–3/4″ • 316SS and brass • for soft plastic tubing

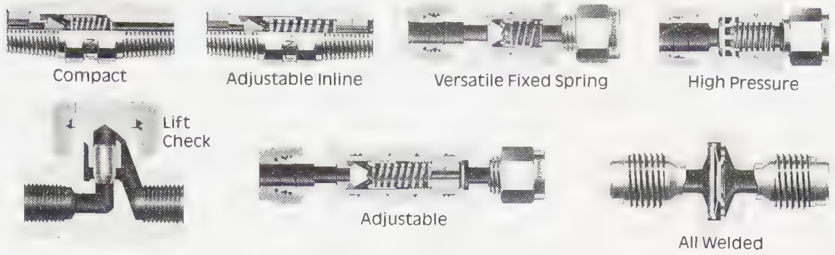


Ball & Plug Valves

1/16″–2″ • variety of stem packings, seat packings, and body seals • 316SS, brass, alloy 400, carbon steel • to 850°F and 6000 PSI

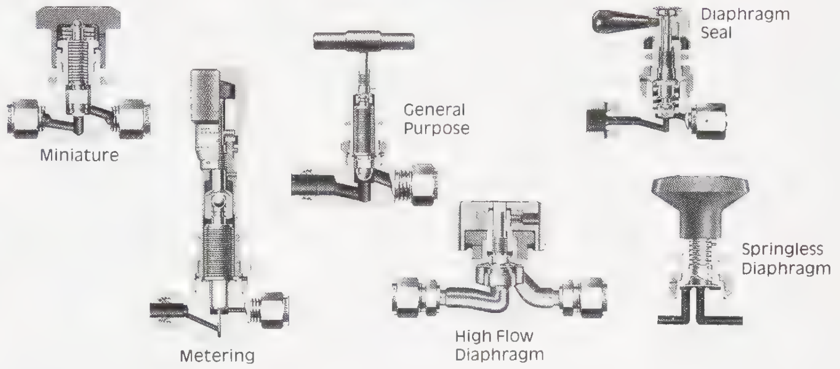
Check Valves

1/16″–1″ • 316SS, brass, alloy 405, carbon steel • working pressures to 6000 PSI • cracking pressures 1/3 to 100 PSI



Packless Valves

1/4″–1″ • 316SS • to 1200°F and 3500 PSI

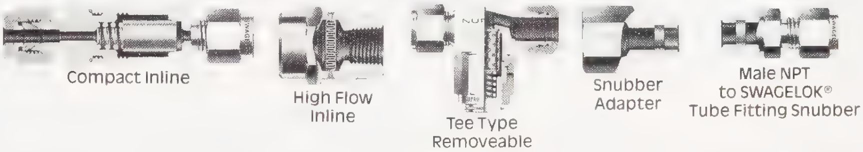


Metering Valves

1/16″–3/8″ • 316SS, brass, alloy 400 • to 400°F and 2000 PSI

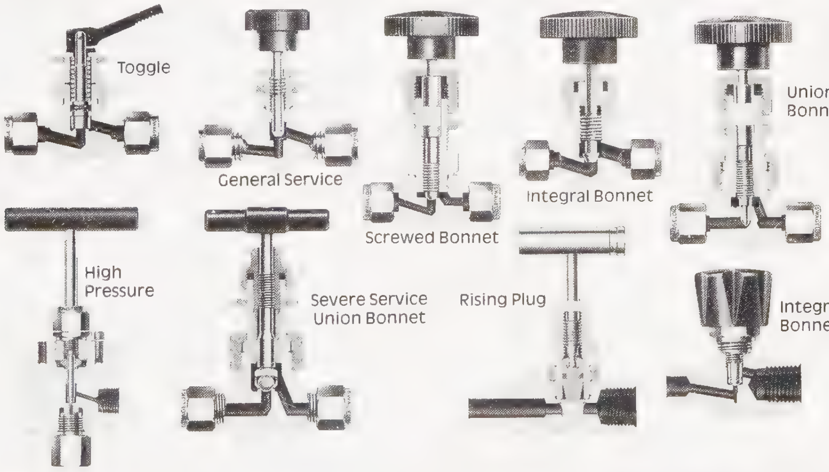
Filters & Snubbers

1/8″–1/2″ • 316SS and brass • to 900°F and 6000 PSI



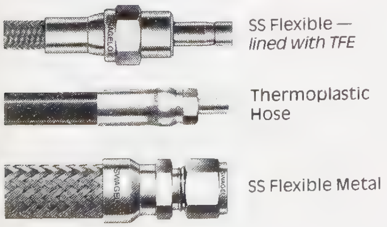
Needle Valves

1/8″–1″ • 316SS, brass, carbon steel • to 1200°F and 45,000 PSI



Hose Products

1/4″–1″ • variety of lengths and end connections • to 1200°F and 5000 PSI



These Products are subjects of patent or patents pending

The products of the SWAGELOK® companies provide standards of *leak-free performance* that meet today's requirements for safety, reliability, and cost-saving operation.

Your Authorized Sales and Service Representative stocks all product lines for immediate delivery. Regional inventories back up local stocks to maintain service levels that meet your needs on every order.

the SWAGELOK® companies

SWAGELOK Co., Solon, Ohio 44139
SWAGELOK Canada Ltd., Ontario

1989 SWAGELOK Co., all rights reserved FD-0-009

Circle 455

35 Million Man-hours without a Lost-time Injury

“Valves and Fittings from the SWAGELOK® companies help make it possible”

The DuPont Company's Jackson Laboratory has made impressive contributions to many DuPont businesses. That's a fact that makes Dr. J. Peter Jesson, Laboratory Director, extremely proud.

Pride in Safety

Here's another fact in which Dr. Jesson takes great pride: Jackson Laboratory, beginning in 1965, accumulated 35 million man-hours without a lost-time injury caused by equipment failure.

This is in spite of the fact that research often requires working with corrosives, carcinogens, and flammable and explosive materials, as well as high pressures and temperatures.

A Record of Reliability

How has DuPont been able to achieve this record?

“Valves and fittings from the SWAGELOK companies help make it possible,” says Dr. Jesson. “Their large product line means they can handle a very wide range of applications. And they're designed and manufactured to the highest standards. We can install these valves and fittings and know that we will have safe, very reliable facilities.

Dr. J. Peter Jesson, *Laboratory Director* Jackson Laboratory, DuPont

“I know this because we've worked with these products for over 25 years.”

They'll work for You

These are the same valves and fittings that will provide precise control and leak tight containment in your fluid systems. You can select from a variety of sizes, shapes and materials. And you can order them today from your Authorized Sales and Service Representative.

the SWAGELOK companies

SWAGELOK Co., Solon, OH 44139
SWAGELOK Canada Ltd., Ontario

© [illegible] Swagelok Co., all rights reserved [illegible]

Circle 455

break up toward the end of service lives.

Also, most manufacturers can furnish filter housings that will adequately support the filter element and restrain the fluid. Make sure that the housing selected allows easy servicing: An inconvenient filter simply isn't changed or serviced often enough, to the detriment of the hydraulic system. The housing should open quickly with a minimum of tools for element changes.

If the flow of filtered fluid cannot be interrupted, a duplex filter can be used. A duplex provides two filters separated by a three-way valve. Flow continues through one while the other can be serviced. Or if the system must be continued in operation, but can tolerate short periods of unfiltered flow, a conventional filter with a servicing bypass can perform the same functions as a duplex unit.

Bypass valves in filters must be capable of handling the maximum flow that can be expected through the filter assembly if it clogs up. With full flow through the bypass valve, the orifice should be large enough to avoid excessive differential pressure on the filter element. Bypass valves should be located so that collected dirt on the filter element is not swept downstream by the flow of oil passing through the valve.

Differential pressure indicators are options on nearly all filter housings; they are useful and should be considered. Typically, they inform operating personnel of accumulated contaminant buildup in the filter, and provide danger signals so that the elements can be serviced.

The devices include electrical switches, continuous-reading visual indicators, visual indicators with memory. The memory indicators show the highest differential pressure that the filter element has experienced, and are useful for jobs where an operator cannot watch the differential-pressure indicator continuously.

Air dryers

Water vapor is contained in high-pressure air. In vapor form, the water does little damage in most components. But if the water is allowed to condense in the system, it can rust pipes, freeze up actuators, and damage a process, tool, or instrument.

Manufacturers of pneumatic components normally specify that air of a certain dryness be supplied for best operation. For example, some pneumatic instruments and logic elements require ultradry air; at the other end of the scale, most pneumatic hand tools require only that moisture not actually turn to liquid during the air-expansion process.

Main-line pneumatic system dryers are installed close to the compressor, usually between the air receiver and distribution lines. Such a unit dries the whole pneumatic system in a plant and prevents a host of filtration problems throughout the system. Individual dryers may be used directly upstream of specific components that require dry or ultradry air. For providing either mainline or point drying, three types of dryers can be used.

Deliquescent dryers are simply large pressure vessels filled with a chemical having an affinity for water — salt, urea, and calcium chloride are common. As the compressed air passes through the vessel, the salt dissolves in the water vapor and drips to the bottom of the tank where it is drained. The dried air is then discharged through the outlet port at the same temperature at which it entered.

Deliquescent air dryers are inexpensive and simple; however, they require that the salt be replenished regularly. In addition, the corrosive salt solution can cause drain traps to clog. Also, a fine salt mist can be entrained in the air and be carried downstream to corrode system components.

Deliquescent air dryers can suppress the dew point by only about 20°F below the inlet temperature. Newer models are somewhat more efficient, but these types are limited to inlet air temperatures of 70°F or lower.

Refrigerated air dryers remove moisture from air by cooling it so that water vapor precipitates out. Where dew point requirements are above 32°F, these dryers are the most economical choice because of their low initial cost. They are available for a wide range of dew point requirements —

HIGH-EFFICIENCY FILTRATION

Coalescing filters remove water and oils as they pass through the element. As liquids and aerosols come in contact with a fiber, they combine with other aerosols on the fiber to form droplets, which are subsequently carried through to the outer surface of the filter element. Here, the droplets drain to the bottom of the element and housing, where they are removed through a manual or automatic drain.

Coalescing filters rated to 0.3 μm protect highly sensitive pneumatic equipment such as logic elements, bearings, high-speed tools, and robotics. Filters rated at 0.7-μm remove general contamination in standard industrial applications.

Putting these elements together in a system is the key to high-efficiency filtration.

1. Determine flow rate through the filter, inlet pressure, maximum temperature, and pipe size.
2. Consider the maximum allowable pressure drop across air-treatment components. Never undersize filters so that they become a restriction. Excessive pressure drop increases operating costs.
3. Determine air quality required for the application, and match filters to meet requirements.
4. Install filters downstream of air receivers, aftercoolers, and moisture separators. This prolongs the life of filter elements, because bulk contamination is removed before reaching the filter.
5. In systems with excessive particulate and liquid contamination, place a particulate filter before the coalescing filter. This prolongs the life of the coalescing element and prevents a premature drop in pressure across the filter. Particulate filters should also be placed after desiccant dryers to prevent desiccant dust from migrating downstream.
6. Always provide enough room below filter housings to remove the bowl and change elements.
7. Use automatic drains on housings for condensate removal. This minimizes maintenance and ensures high-filtration performance.
8. Adsorber filters remove oils and hydrocarbons to 0.002 ppm and are used to eliminate odors and hydrocarbon vapors. Always place a 0.3-μm coalescing filter before an adsorber.
9. Replace coalescing elements when pressure drop across the filter exceeds 8 psig. Differential pressure indicators attached to the filter housing are recommended.

AIR SYSTEM GUIDELINES

Designing and maintaining a good air-preparation system is not difficult. Following some basic guidelines ensures top performance and long life for pneumatic components.

- Drain filters regularly. Automatic drains are recommended because filter maintenance is often neglected. A filter bowl filled to capacity impedes air flow.
- Clean or change filter elements regularly, or at the first sign of power loss downstream. Do not rely on a visual inspection of the element — it can be filled to capacity and yet look like new.
- Design a system for the worst ambient conditions that it will encounter, not the norm. A common problem is that systems perform well for most of the year, and then experience water problems in the summer. Adding a dryer after the fact may require substantial changes to equipment already in place.
- Provide sufficient line runs between compressor and air-preparation components to allow cooling of discharge air. Excessive heat can quickly degrade seals and plastic components. If adequate space is not available, add a cooler to the system.
- When lubrication is necessary, use one lubricator per pneumatic device. Operating several components on air from a single lubricator results in one unit receiving most of the lubrication, while the others receive little or none.
- Constant seal failure or degradation of plastic components may point to a compatibility problem. Check the compressor oil; certain synthetic oils, in particular, will attack plastics and elastomeric seals.
- Piping should slope away from the compressor at a rate of about 1 in. per 10 ft. This allows condensate to flow to a low point, where an automatic drain or drip leg should be installed. Branch lines should extend from the top of main lines. This allows air to flow into the branch, while any sediment or water tends to remain behind.
- Undersized lines, connections, and even filters are frequently encountered. Choking off air flow wastes energy and underpowers downstream components.

from 33 to 100°F — and require little operator attention. Refrigerated dryers cannot suppress dew point below 33°F because ice forms and clogs the heat exchangers.

Generally, refrigerated air dryers use two heat exchangers in series to condense entrained moisture and reheat the outlet air. Most dryers of this type precool the incoming air before it reaches the refrigeration chiller. Precooling reduces the load on the chiller so that smaller, less-expensive heat exchangers and compressors can be used.

The precooling arrangement is usually an air-to-air heat exchanger that uses outgoing cold air to cool the inlet air. Since this setup requires cold air to precool inlet air, the dryer has a start-up delay before it reaches the required dew point.

Where slow start-up cannot be tolerated, dryers employing air-to-refrigerant heat exchangers are available. Although more costly than standard designs, these dryers provide a nearly constant dew point, even with fluctuations in air flow and ambient temperature.

Desiccant dryers use nonconsumable chemicals such as silica gel or active alumina, and can remove almost all the moisture from compressed air. A desiccant dries air by adsorbing moisture on its surface and holding the water as a mono or biomolecular film. The method of regeneration, the process of removing adsorbed water from the desiccant, is the primary distinguishing feature among the various types of desiccant dryers.

Most regenerative desiccant dryers are dual-chamber systems with one chamber on-stream drying the compressed air while the other is off-stream being regenerated. There are three ways to regenerate a desiccant: with air, internal or external heaters, or a heat pump.

Heaterless dryers regenerate desiccant by passing a quantity of the dried air through the offstream vessel. These dryers are the most expensive desiccant types to operate because they require high purge air flows to regenerate the desiccant. For example, a pressure dew point of −40°F uses about 14% of the compressed air flow for regeneration. To minimize air usage, some dryers are equipped with controls so that purge rate can be adjusted to accommodate variations in ambient temperature.

Heaterless dryers produce dew points down to −150°F. Maintenance costs are low because they have few moving parts, and desiccant can last 10 to 15 years if the air is prefiltered to prevent oil contamination.

Heat-regenerative dryers are similar to heaterless dryers except that the desiccant vessels contain heating elements. Depending on the amount of heat applied, these types still require 2 to 6% purge air flow to produce a pressure dew point of −40°F. The less purge air used, the higher the cost of power to run the heaters.

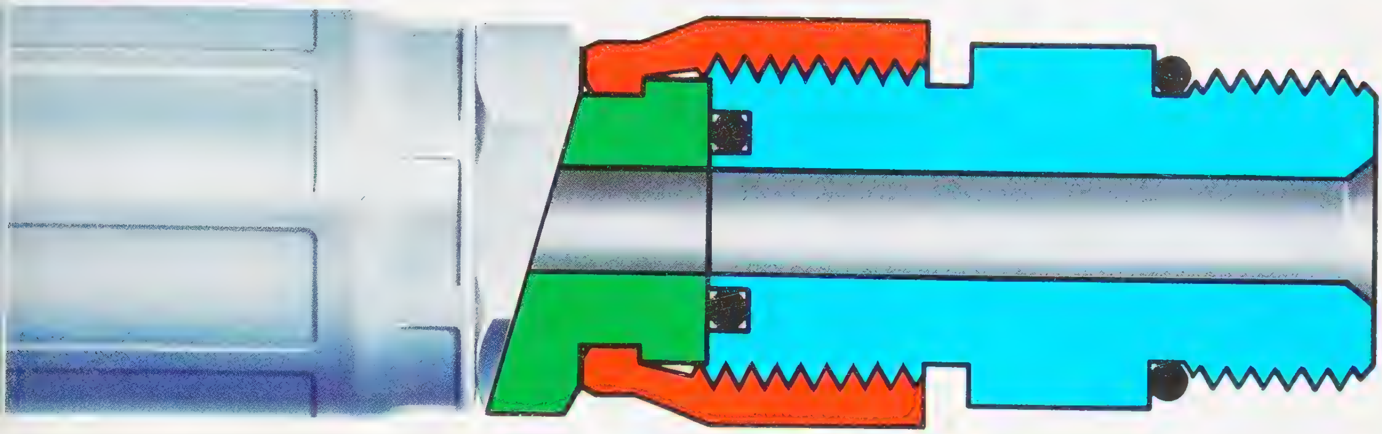
Heat-regenerative dryers have the same dew-point range as heaterless types. However, since high regenerative temperatures can damage equipment and desiccant, maintenance costs and downtime can be higher.

Heat-pump dryers combine the best features of heaterless desiccant and re-

Selection guidelines for compressed-air dryers

Dryer type	Pressure dew point range	Initial cost	Operating cost	Typical applications	Remarks
Deliquescent	12 to 20°F below inlet temperature	Lowest	Low to moderate	Protection against condensation in indoor air lines	Salt solution in air lines causes high maintenance of downstream equipment
Refrigerated	Above 33°F	Low	Low	General plant air; air-operated tools, instruments, material conveying	Most widely used type because of inherent reliability and low cost
Desiccant heatless	33 to −150°F	Low to moderate	Highest	Outside air lines, chlorine padding, manufacturing processes requiring very dry air such as assembling electronic equipment and making urethane foam	High purge rate causes inefficent operation
Heat regenerative	33 to −150°F	Moderate to high	Moderate to high		High maintenance and downtime for component and desiccant replacement
Heat pump	33 to −100°F	High	Low to moderate		Very efficient with little maintenance required

Starts dry.



Stays dry.

Be sure with Parker's Seal-Lok™ system.
With Seal-Lok, assembly is right and dry – the first time.

The burly nut is hand tightened – then torqued down with a single pull of the wrench – to give you that solid "hit-home" feeling – and a leak-tight connection.

The face of every Seal-Lok fitting is machined flat and smooth to fit flush against the adapter.

The O-ring in the adapter is made of a special 90 durometer elastomeric compound that compresses against the flat face of the fitting. The higher the working pressure, the more effective the seal, up to 6,000 PSI.

Seal-Lok assemblies are available factory made. Or, as "do-it-yourself" assemblies made with the Parkrimp field-crimp system.

For further information, see your Parker distributor or contact Parker Hannifin Corporation, **Hose Products Division,** 30240 Lakeland Boulevard, Wickliffe, Ohio 44092. Phone (216) 943-5700.

Parker
FluidConnectors

Circle 458

HP-324

frigerated dryers. These dryers use refrigeration cooling to remove most of the incoming moisture and to cool the onstream vessel for maximum adsorption efficiency. Thermal energy from the inlet air then is used to heat the offstream vessel and a small amount of purge air for regeneration.

In this type of dryer, a −40°F pressure dew point requires 1.5% purge air flow to regenerate the desiccant. Thus, heat-pump dryers have considerably lower operating costs than the other types.

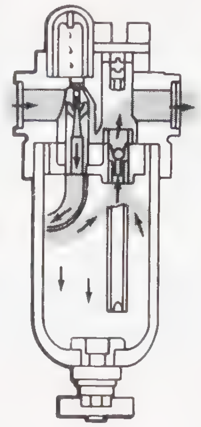
Heat-pump dryers produce stable dew points down to −100°F. Also, because regeneration takes place at a lower temperature, the hazards and maintenance problems of heat-regenerated dryers are eliminated.

Pneumatic lubricators

The increased use of manifolding, complex valves, and miniature components have increased the difficulty of transmitting lubricants to pneumatic components. The problem is to get enough oil to the components without flooding them. Even in a straight line, oil particles with diameters larger than about 80 μin. tend to coalesce within about 25 ft from the lubricator. They form pools in the bottom of the line, and must depend on the sweeping action of the air to reach their intended destination.

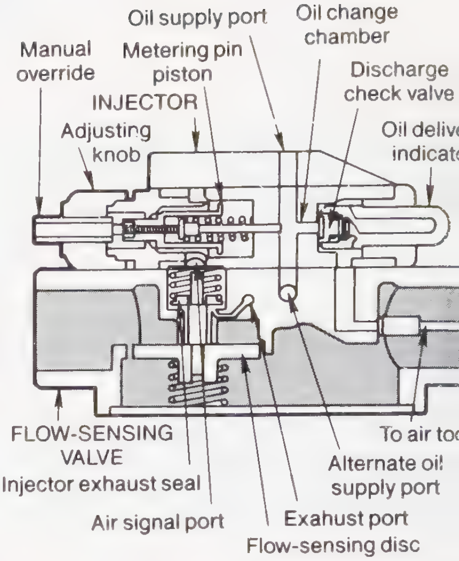
Manifolds and complex valves contribute to this coalescing action by inserting restrictions and turbulent areas in the flow path. Smaller components use less air, so oil particles take longer to reach their destination.

But these difficulties are not insurmountable. Flow paths that are too tortuous or lengthy for a direct-flow lubricator may present no problem to a recirculating flow lubricator. And pulse lubricators are available for still more difficult applications.


DIRECT-FLOW LUBRICATOR

Direct-flow lubricators spray a mist of oil directly into the air line. They are inexpensive, and can adequately lubricate most pneumatic systems if air lines are reasonably straight, do not exceed about 25 ft in length, and include no sections where air must rise vertically. Oil particles emitted from direct-flow lubricators have diameters ranging from 0.4 μin. to 0.02 in. About 96 to 97% of these particles are larger than 80 μin., and tend to coalesce on air lines fairly rapidly.

Recirculating-flow lubricators are similar to direct-flow lubricators, except that they recirculate misted oil past a baffle and into the bowl. Large particles remain in the bowl because of their mass, and medium particles coalesce on the baffle. As a result, particles injected into the air stream have diameters ranging from 0.4 to 80 μin. These smaller particles can traverse up to 100 ft of straight pneumatic line. Recirculating-flow lubricators cost about the same as comparable direct flow models, but cannot be refilled under pressure.



Pulse lubricators do not spray an oil mist into the line, but instead inject a small, accurately measured amount of liquid oil directly into a pneumatic actuator. Because the injection point is at the actuator, the length and complexity of the pneumatic line leading to the actuator is irrelevant. The amount of oil directed to each actuator can be controlled individually to match actuator requirements. Pulse lubricators are mechanically more complex and more costly than either direct-flow or recirculating-flow lubricators.

Hydraulic hose

Hose is widely used in applications where lines must flex and bend. System pressure, pressure pulses, fluid velocity, temperature, fluid, and environmental conditions form important factors in the use of hydraulic hose.

Pressure: Hoses are impulse tested from 100 to 133% of rated pressure, to allow for transient pressures. Proof pressures are 50% of burst pressure. The SAE recommends that the oper-

SAE J517 Specifications

SAE		Temperature	Dash size vs. working pressure (psi)													
standard	Construction	range (°F)	−3	−4	−6	−8	−10	−12	−16	−20	−24	−32	−40	−48	−56	−64
SAE 100R1	1 wire braid	−40 to + 200	3000	2750	2250	2000	1500	1250	1000	625	500	375				
SAE 100R2	2 wire braid	−40 to + 200	5000	5000	4000	3500	2750	2250	2000	1625	1250	1125	1000			
SAE 100R3	2 fiber braid	−40 to +200	1500	1250	1125	1000	875	750	565	375						
SAE 100R4	Helical wire	−40 to +200						300	250	200	150	100	62	56	45	35
SAE 100R5	1 wire braid	−40 to +200		3000	2250	2000	1750	1500	800	625	500	350	350	200		
SAE 100R6	1 fiber braid	−40 to +200	500	400	400	400	350									
SAE 100R7	Thermoplastic, fiber braid	−40 to +200	3000	2750	2250	2000	1500	1250	1000							
SAE 100R8	Thermoplastic, fiber braid	−40 to +200	5000	5000	4000	3500	2750	2250	2000							
SAE 100R9	4 spiral wire	−40 to +200			4500	4000		3000	3000	2500	2000	2000				
SAE 100R10	4 spiral wire	−40 to +200	10000	8750	7500	6250		5000	4000	3000	2500	2500				
SAE 100R11	6 spiral wire	−40 to +200	12500	11250	10000	7500		6250	5000	3500	3000	3000	2500			
SAE 100R12	4 spiral wire	−40 to +250			4000	4000		4000	4000	3000	2500	2500				
SAE 100R13	4 & 6 spiral wire	−40 to +250						5000	5000	5000	5000	5000				
SAE 100R14	PTFE lined	−65 to +400	1500	1500	1500	800		800	800							

UNDER PRESSURE FOR PERFORMANCE? CHECK WHAT YOU NEED FROM A HYDRAULIC FLUID.

☐ Operation at 5000+ PSI

☐ Superior fire safety

☐ Higher temperatures

☐ Extended pump life

☐ Lower operating costs

UCON®
Hydrolube
HP-5046

☑ All of the above

Now there's a high-performance hydraulic fluid that doesn't compromise on safety, pump life or operating costs.

UCON® Hydrolube HP-5046 is the new generation, high-performance hydraulic fluid engineered for system pressures to 5000 PSI and beyond, and temperatures to 170°F and above.

Approved by Factory Mutual as a Group I Less Hazardous Hydraulic Fluid, HP-5046 won't burn, flare-up or smoke like other synthetic hydraulic fluids. And, in industry after industry, it's been shown to extend pump life up to 100%.

What's more, UCON Hydrolube HP-5046 contains no phenols. No special handling is required, and storage and clean-up are easy.

Check out UCON Hydrolube HP-5046. Call for full information today.

Call 1-800-242-7226
UCON® Hydrolube HP-5046
When the pressure's on for performance

UNION CARBIDE
Specialty Chemicals Division

Copyright ©1991 Union Carbide Chemicals & Plastics Technology Corporation. UCON is a registered trademark of Union Carbide Chemicals & Plastics Technology Corporation

Circle 459

ating pressure be no more than 25% of minimum burst pressure. This is an acceptable safety margin for industrial use, and it also allows the hose to accept some surge pressures.

Size: Required hose size depends on volume and velocity of fluid flow. If fluid velocity is too high, flow is turbulent and energy is lost.

Sizes available for fluid-power applications range from 3⁄16 to 3-in. ID. Sizes are designed in 16ths of an inch by using a "dash" equivalent to the numerator of the fraction. Thus, "—10" is 10⁄16 or 5⁄8-in. size. These dash sizes are marked on the hose.

Temperature: Hydraulic or pneumatic hoses must be able to tolerate both the external ambient and the internal fluid temperatures. A hose with a broad recommended operating range — for example, −40 to 200°F — can accommodate most operating conditions. Some hose elastomers permit operation at rated pressure and temperatures up to 300°F; others are rated for temperatures down to −65°F.

Reinforcement type: The reinforcement may be a natural or synthetic yarn or fiber, a metal wire, or combinations. The reinforcement may be braided, spiral wound, or both.

NON-SAE DESIGNS

In addition to standard SAE hoses, manufacturers produce hoses that do not comply with SAE standards. Using the standards only as a guideline, hydraulic manufacturers have deviated on parameters such as dimensions, number of braids or spirals of reinforcement, and cover material. In most cases, the result is a superior product with added benefits for the user.

One such example is hydraulic hose with one-wire-braid reinforcement that has the same pressure rating as two-wire-braid reinforced hose. The advantages of such hoses include:

- Increased flexibility.
- Less hose needed to plumb a circuit, because the one-wire hose has a smaller minimum bend radius.
- Lighter weight assemblies.
- Less costly than its two-wire counterpart.
- Smaller OD for easier plumbing.

Today, the hose designer is afforded great flexibility in creating new hose constructions. Varying tube materials, thicknesses, wire strengths and diameters, and overall dimensions provides products that are ideally suited to meet specific pressure, fluid compatibility, and cost requirements.

With many proprietary hoses evolving to solve specific application problems, OEMs and other users are becoming less inclined to demand SAE-standard hoses. Thus, market share for non-SAE products continues to grow. However, there is almost universal agreement that SAE standards are not obsolete, and likely never will be. While less attention is paid to dimensional specifications, working and burst pressure and impulse life remain important performance benchmarks. In addition, SAE test methods are well established and widely accepted.

Standard committees have discussed incorporating non-SAE hoses into SAE specifications to provide tighter control over these products. Because standards are typically slow to evolve, with a number of years between product introduction and standardization, today's proprietary products may be covered by future SAE standards.

HOSE STANDARDS

Hose construction has been standardized under SAE J517, better known as SAE 100R-series hoses. Reinforcement and construction vary among these designs, providing different pressure ratings and other specific performance features.

SAE 100R1 is a rubber hose with one-wire-braid construction. Working pressures range from 375 to 3,000 psi, depending on the hose ID, and temperature range is from −40 to 200°F. This hose is commonly used on lower-pressure hydraulic lines.

SAE **100R2** is essentially the same as 100R1, but has two-wire-braid reinforcement. Depending on the hose ID, the added reinforcement raises the working pressure range to 1,125 to 5,000 psi.

SAE **100R3** is a two-fabric-braid reinforced hose with pressure ratings from 375 to 1,500 psi. This hose is more flexible and generally less expensive than wire-reinforced hose and is used in low-pressure applications.

SAE 100R4 is a suction or return-line hose. The reinforcement is fabric braid or weave with a helical-wire strand. The helical wire prevents the hose from collapsing under internal vacuum. Sizes range from ¾ to 3-in. ID.

SAE 100R5 is a fabric-covered hose constructed with two textile braids separated by a high-tensile steel-wire reinforcement. Typical applications include air-brake lines, transmission-coolant lines, and tilt-cab cylinders.

SAE 100R6 is a single-fabric-braid reinforced hose with a low working-pressure range — from 300 to 500 psi. Although not widely used, it is suitable for low-cost, low-pressure applications.

SAE 100R7 has a thermoplastic tube and cover, and a single-fiber-braid reinforcement. Pressure range is the same as that for SAE 100R1 hose. Advantages include light weight, greater chemical resistance, and better internal tube cleanliness than comparable rubber hose. Disadvantages include a maximum 1-in. ID and a tendency for the hose to become stiff and brittle at low temperatures. Thermoplastic hose can be specified as nonconductive for use on bucket trucks and cherry pickers.

SAE 100R8 is a thermoplastic hose with construction similar to that of 100R7 hose, except that the reinforcing layer contains more fiber or has a tighter pack. Pressure ratings are the same as SAE 100R2 hose.

SAE 100R9 is a rubber hose with a four-spiral-wire reinforced construction. Pressure range is from 2,000 to 4,500 psi. Because of the high-pressure ratings on 100R9 through 100R13 hoses, they are widely used on construction, mining, and heavy mobile equipment.

SAE 100R10 is also a four-spiral, wire-reinforced construction hose. Working pressures range from 2,500 to 10,000 psi, exceeding that of SAE 100R9.

SAE 100R11 is a rubber hose with six-spiral-wire reinforcement with a pressure range of 2,500 to 12,500 psi.

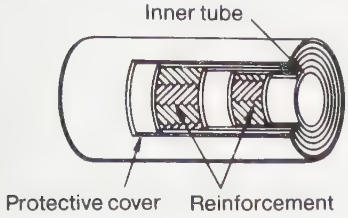
SAE 100R12 is a four-spiral, wire-reinforced hose with working pressure range of 2,500 to 4,000 psi.

SAE 100R13 is a four or six-spiral, wire-reinforced hose with a 5,000 psi working pressure for the entire size range. It is usually the hose of choice on hydrostatic transmissions.

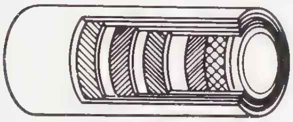
SAE 100R14 hose has aPTFE inner tube and braided-wire reinforcement. PTFE allows compatibility with a wide variety of fluids and temperatures to 400°F.

Wire-braid reinforcement, commonly used for hydraulic applications, provides good service life at moderate cost. The wire is usually braided with 2 plaits over 2, which is economical and reliable with good dimensional stability.

Spiral wire-wound hoses are often used for applications with high-frequency surges in high-pressure systems. As pressure surges, normal braided reinforced hoses tend to fail at the wire crossover points in the weave. These points cause bending and shear in wires that are already highly stressed. The advantage of spiral wire reinforcement is that it eliminates touchy crossover points permitting up to 97% of theoretical total coverage.



100R2A HOSE



Four-ply, light-spiral-wire reinforcement
100R9 HOSE

Hose fittings

Wrong fittings can render even the best hose useless. The best systems require the right type of fitting, using the right attachment method, and made of the right material. Fittings and hoses can be assembled in-house or purchased as assemblies from manufacturers.

Fittings types: Most fittings can be categorized as either reusable or permanently attached. Reusable fittings are screwed onto a hose or are bolted together. They can be removed from a failed hose and installed on a new one. Thus, they can save money, and time as well. Permanent fittings, such as crimped or swaged fittings, are squeezed onto the hose at assembly. As the name implies, these are only for onetime use, and must be discarded when the hose assembly fails. However, these fittings generally cost less than reusable fittings, and require less time to make a hose assembly.

Materials: Fittings are available in a wide variety of materials; material selection is usually based on compati-

ABRASION-RESISTANT HOSE

There is increasing demand for hydraulic hoses that are protected by abrasion-resistant coverings. The growing use of abrasion-resistant hose is primarily driven by the push to cut product costs. One cost-reduction method is to make machines smaller and lighter, but downsizing can lead to service problems. On mobile equipment, for example, a scaled-down machine has less room for the engine, transmission, and drivetrain, not to mention the hydraulic plumbing. Consequently, hydraulic lines often have to be routed in a less than optimum fashion. In many cases, hose rubs against portions of the frame, sheet metal, moving parts, or other hose.

Vibration and movement often result in premature hose failure. The cover abraids, exposing wire reinforcement to the atmosphere and elements, leading to corrosion, weakening, and eventual failure. This premature failure also causes another problem: machine downtime. The end user or service personnel must spend time removing the failed assembly, and obtaining and installing a new one.

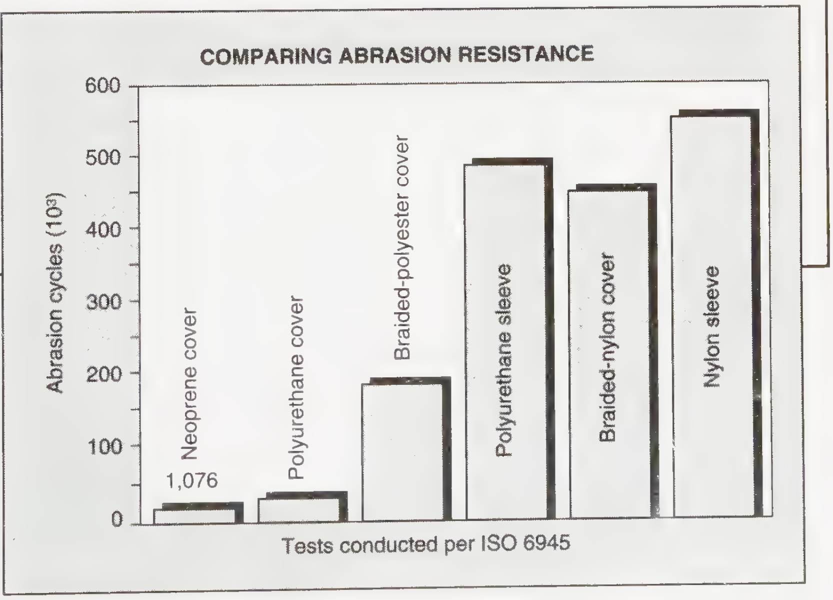
To solve the problem, OEMs place abrasion-resistant sheathing over standard hose, or use hose with an abrasion-resistant cover built in. Responding to the OEM demand, most hose and coupling manufacturers have developed a variety of abrasion-resistant hoses and coverings.

Slide-over coverings: Slide-over, abrasion-resistant sheathing comes in a variety of constructions and sizes. The most common types are a nylon-weave construction or an extruded-thermoplastic construction — usually of polyurethane. A wide variety of sleeve sizes allows for bundling or grouping a number of hoses together inside a single sleeve. This sheathing has excellent abrasion resistance compared to standard hose-cover materials, such as neoprene or polyester textile braids.

Drawbacks to using the slide-over sheathing include the additional cost and time required during the hose assembly process. After a hose is cut to length and the couplings attached, the covering must be pulled over the hose and secured in place.

Built-in resistance: A more efficient method is to build abrasion resistance right into the hose. Many manufacturers now offer this type of hose in several SAE 100R constructions, as well as "hybrid" constructions. (Hybrid-hose dimensions may conform to an SAE 100R specification, but performance characteristics exceed those mandated in the spec.) The hose cover materials provide exceptional abrasion resistance compared to standard rubber-covered or textile-braid covered hose.

These developments in abrasion-resistant hose mean end users have less machine downtime due to hose failure. For their part, OEMs can now tailor hydraulic plumbing to fit downsized equipment with less worry about hose abrasion problems in the field.



bility with the fluid and the environment. Carbon-steel fittings are most widely used for both high and low-pressure hydraulic systems. Stainless steel, brass, or Monel can be used for systems carrying corrosive fluids or systems used in corrosive environment. Fitting suppliers can provide a detailed list of materials available and the fluids that they can handle.

Connections: Hose fittings terminate in a wide variety of connections that can be used to mate with the components in the system. Most common connections are pipe thread, split-flange, straight thread, O-ring seal, and 37° joints. Pipe threads have limited use on high-pressure systems; otherwise, all of the systems work for their appointed tasks.

High-pressure permanently attached fittings are usually factory assembled on to a standard hose that has been stripped to the bare metal ("skived"). If crimped, the fitting is attached by squeezing the socket to compress the hose between the inner nipple and the radially squeezed socket. Swaged fittings are assembled by drawing a fitting through a tapered die to reduce the outside diameter. These fittings tolerate working pressure to 12,500 psi.

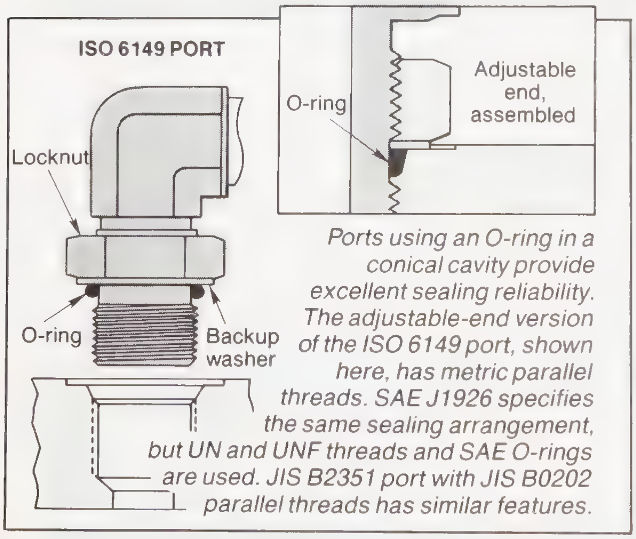
HIGH-PRESSURE PORTS

There is general consensus among hydraulic designers and fitting specialists that a port with an O-ring in a conical groove offers the best high-pressure performance. SAE J1926, ISO 6149, DIN 3852, and JIS B2351 all specify the same sealing concept — straight-thread fittings with elastomeric sealing — and provide comparable performance.

SAE straight-thread ports have UN or UNF parallel threads and seal with an O-ring in a conical cavity, which provides excellent sealing reliability. The fittings are widely used in the U.S. and Canada, and SAE seal availability is considered to be better throughout the world than for other types of seals.

ISO 6149 ports also seal with an O-ring in a conical cavity, but they feature metric parallel threads. They are, in essence, metric versions of SAE straight-thread ports. In fact, the standard was developed as a metric alternative to SAE. Currently, it is not widely used, and is considered to be more of a paper standard.

British straight-thread ports have British Parallel Pipe Threads (BSPP). British thread forms use sizes similar to SAE (inch dimensions), but are not interchangeable. For this reason, they are often mistaken for metric threads. Japanese parallel threads (JIS-PF) are essentially the same as BSPP threads. A number of sealing variations are offered; the most reliable is considered to be an O-ring with retaining ring. The fitting is widely used in the United Kingdom, France, Scandinavia, Japan, and British Commonwealth countries.



Ports using an O-ring in a conical cavity provide excellent sealing reliability. The adjustable-end version of the ISO 6149 port, shown here, has metric parallel threads. SAE J1926 specifies the same sealing arrangement, but UN and UNF threads and SAE O-rings are used. JIS B2351 port with JIS B0202 parallel threads has similar features.

DIN 3852 features true metric threads. It also allows many sealing variations, with an O-ring and retaining ring, or a trapped seal ring, offering the best high-pressure performance. DIN 3852 is the only port rated to 9,000 psi, although there is some question whether this is a true dynamic pressure rating. The port is widely used in West Germany.

Four-bolt split flanges seal with an O-ring in the flange head, and are widely used around the world. While SAE specifies UN and UNF bolts, metric bolts are substituted in the ISO proposal.

Medium-pressure screw-assembled fittings are commonly used for SAE 100R5 series hose plus some air and refrigerant hoses. With these fittings, no special preparation of the hose (other than lubrication) is required before assembly. Such fittings are suitable for hydraulic and air applications to 5,750 psi.

Field-assembled permanently attached fittings are similar to the swaged or crimped hoses, but are assembled on special portable crimping or swaging machines. Field-assembled units are typically not skived; instead, SAE 100R hoses with thin covers are used. They can handle pressures to 5,000 psi.

Bolt-on and segmented reusable fittings are typically used on large hoses. They are suitable for both air and hydraulic applications, as well as a variety of other fluids, at working pressures to 4,000 psi.

Pipe and tubing

Pipe and tubing are used when rigid lines are preferred. No matter which conductor is used, certain requirements must be met. The line must be large enough to carry the flow required, and it must be strong enough to withstand internal pressures.

Line size can be determined from the amount of fluid that must be carried and the maximum velocities at which the fluid may travel. Normally, good design practice dictates that fluid velocities should not exceed:

- Pressure lines — 10 to 15 fps.
- Short pressure lines — to 20 fps.
- Inlet or suction lines - 2 to 5 fps.

To determine the required wall thickness of pipe and tubing, apply this basic equation: $T_t = pd_oM/2S$, where p = pressure, psi; d_o = outside diameter, in.; M = safety factor; and S = material tensile strength, psi.

Pipe selection: Pipe generally costs less than tubing, and is normally used where:

- The pipe can be connected directly to pipe-threaded connections on system components.
- Disassembly is improbable or very infrequent.
- Large volumes of fluid must be handled, or where the line is long and straight.

Outside pipe diameter conforms to the corresponding series for pipe threads. Therefore, the outside diameter of each nominal size remains constant regardless of wall thickness. Today, the range of wall thicknesses available provides an equivalent range of inside diameters. Inside and outside

Introducing

Parflex TrueSeal

The world's first all-plastic quick-connect tubing fitting

Parflex announces a new line of all-plastic fittings with the features you'll appreciate! TrueSeal all plastic, metal-free, push-in tube fittings won't leak even when sideloading is encountered. Easy installation: No special tools needed!

Features You'll Like!
TrueSeal fittings feature an engineered polymeric grab ring that eliminates possible metal corrosion. Hassle-free, easy installation eliminates the possibility of tube damage during connection and disconnection. All-plastic construction eliminates worries over system purity and environmental concerns. A positive stop assures proper assembly every time!

Great for your tight spots!
In a tight spot? You'll like TrueSeal's easy installation in confined areas without special tools. Easy assembly: Just insert the tubing into the fitting and that's it. No metal parts to score tube surfaces and create leak paths.

TrueSeal Fittings: Made In The USA
Parflex TrueSeal fittings are manufactured in the U.S.A. and enjoy many of the same high engineering and quality standards that you've come to expect from Parker.

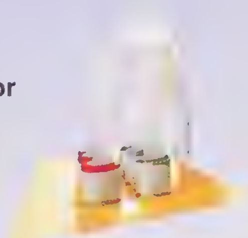
Variety of sizes, types, colors!
Whatever your tubing fitting needs, you'll find TrueSeal all-plastic fittings offer a great selection. TrueSeal is available in sizes from 1/4" through 1/2" and includes straights, swivels, tees and elbows. Special color-coded locking clips provide added safety and line coding capability.

Environmentally friendly!
TrueSeal all-plastic fittings eliminate your environmental worries! No corrosion or contamination that are associated with metal fittings. TrueSeal fittings are compatible with a wide range of media, and are ideal for applications where fugative toxins and system purity are important.

Applications galore!
You'll find TrueSeal plastic fittings are great for a variety of applications. Whether it's water, beverage, air or low-pressure hydraulic systems, TrueSeal's unique O-seal design provides maximum protection against leakage, with chemical compatibility from A to Z.

TrueSeal delivers dry connections
Parflex TrueSeal plastic tubing fittings are specially designed to overcome sideloading without leaks. Working pressures to 300 psi.

See your Parker/ Parflex distributor
Put TrueSeal all-plastic fittings to work for you! See your nearest Parker/ Parflex distributor, or call toll-free 1-800-C-PARKER for the name of the distributor nearest you. Or, for more information, contact the Parflex Division of Parker Hannifin, 1300-A North Freedom Street, Ravenna, Ohio 44266.



Call Toll-Free
1-800-C-PARKER Dept. 123

PA-233

The World Standard

Parker
FluidConnectors

Circle 460

diameters in nominal pipe sizes are listed in any standard reference source.

The pipe schedules most commonly used for hydraulic systems are schedule 40, nearly equal to the former "standard" designation; schedule 80 (formerly extra heavy); and schedule 160 (somewhat lighter than the former double extra heavy). Wall thickness tolerance for all commercial quality pipe is +12%.

Experts recommend that the following safety factors be used for noncritical applications:

- 6 for systems in which hydraulic shock, vibration, and extra stress are not expected.
- 8 for average system conditions.
- 10 for systems where considerable pressure shock or mechanical abuse is expected.

Tubing selection: Tubing is stronger and neater than pipe, and has a wider variety of fittings. Whereas pipe is relatively rigid and unbendable, tubing is easily bent into forms required for a system. Four common materials are normally used for tubing.

Steel tubing is the only type permitted by JIC standards without restrictions. Both seamless and electric-welded tubing meet requirements.

Copper tubing is restricted by JIC standards to low-pressure stationary applications and air circuits because it acts as an oil-oxidation catalyst and tends to work harden when flared. In addition, copper tubing has poor resistance to vibration.

Aluminum tubing of seamless quality has good bending and flaring properties and is approved by JIC for low-pressure tasks.

Plastic tubing is made from four basic materials: PVC, polyethylene, nylon, and PTFE. PVC can be used for pneumatic lines at pressures to 125 psi with continuous temperatures to 100°F. It can be used with compression tube fittings designed for plastic tubing and has excellent abrasion resistance, but loses flexibility below 30°F.

Polyethylene tubing is used for liquids and gas lines at temperatures from −60 to 160°F. Compression fittings are acceptable.

Nylon tubing is used for pneumatic lines and low-pressure hydraulic lines to 250 psi. It is useful at temperatures from −60 to 200°F. Nylon has good impact and abrasion resistance but some nylons can be damaged by moisture.

PTFE tubing can be used to 400°F and 1,000 psi in certain sizes.

Tubing sizes are designated by a dash system in which the number given

ENSURING HOSE COUPLING RETENTION

Safety and performance are two essential characteristics of any hydraulic system, and hose coupling retention has a large bearing on both areas. Improper retention results in less than adequate system performance, leakage, and even coupling blow-off that can lead to catastrophic machine damage and, on occasion, person injury or even loss of life.

Several key factors directly affecting retention of permanent-style hydraulic couplings to hose include:

Abuse: Severe environmental or operating conditions such as pressure spikes exceeding the maximum rating; environmental conditions such as saltwater, acids, or other chemicals; and damaging blows directly on the assembly often mean less than optimum coupling retention.

Temperature: Internal hydraulic system temperatures below −40°F or exceeding 250°F could result in less than adequate coupling retention. Temperature extremes can distort or deteriorate a hose, making coupling retention more difficult.

Fluid/hose incompatibility: The wrong combination of hose and fluid almost immediately results in hose deterioration. For example, hydraulic system designers should avoid petroleum-based fluids with butyl rubber and EPDM hose tubes; diesters with neoprene and Buna-N; phosphate esters (and phosphate ester-based emulsions) with Buna-N; and diesel fuel with Hypalon rubber compounds.

Improper crimping: Frequently, coupling retention is adversely affected by improper crimping. Overcrimping a permanent coupling can deform or damage the hose wire reinforcement or the coupling, leading to eventual assembly failure. Undercrimped, the assembly could fail at normal working pressure by leaking or coupling blow-off.

Misapplication: One of the most common causes of hose/coupling failure is misapplication, including factors such as overpressure conditions, too tight a bend radius, and insufficient length, in addition to temperature and fluid factors.

Mixing of components: Hydraulic components from various manufacturers are not necessarily interchangeable. It is an ill-advised practice to make hydraulic assemblies by using components from different manufacturers. Thus, it is strongly recommended that hydraulic system designers specify hose, coupling, and crimping equipment from one source to assure having a performance-proven hose/coupling system.

SELECTING A COUPLER

Connection force: Connectors that must be coupled under residual pressure may require high connection force. If required force exceeds about 50 lb, an integral bleeder valve will relieve pressure.

Disconnection force: Force required to open the connector under pressure is important in many industrial and mobile applications. Here, disconnection force should be substantially less than that required to break the hose.

End fittings: Quick-action couplers are usually supplied with female NPT fittings, although other end fittings are available on request. End fittings on the coupler must match those on the hose.

Flow: High flow surges can work seals out of their grooves, so seal retention features should be carefully evaluated. In addition, high flow rates induce high pressure drops across the connector, causing structural damage.

Fluid: Not only seals, but metal bodies must be compatible with the hydraulic fluid. Stainless-steel bodies are recommended for corrosive fluids and some phosphate-ester fluids.

Pressure: Catalog pressure rating must not only be greater than nominal system pressure, it must also be greater than maximum surge pressure. Depending on the manufacturer, the ratio of burst pressure to operating pressure rating can range from 2:1 to 4:1.

Spillage: A double-poppet connector spills more fluid on opening than a sliding-seal connector. Even in applications where spillage is "merely" an annoyance, reduced spills may justify the higher cost of the sliding-seal device.

MEETING YOUR PNEUMATIC CIRCUIT NEEDS WITH COMPLETE PRODUCT AND SYSTEM RELIABILITY

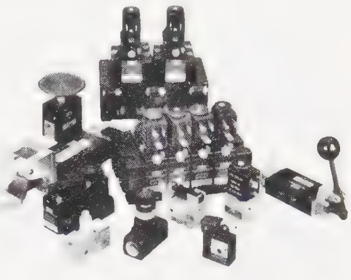
All ARO® Fluid Power products are designed, built and tested to meet the most demanding customer needs. ARO products deliver clearly superior performance in the most challenging in-plant and O.E.M. applications. Aro has a wide selection of Fluid Power products which allow design criteria and specific application requirements to be met with maximum flexibility.

ARO

Part of worldwide Ingersoll-Rand

Pneumatic Valves

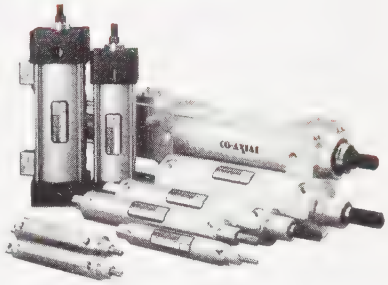
- Manifold Valves – 1/8", 1/4", 3/8", and 1/2". TTL-compatible, micro-relay connectors.
- Spool and Poppet Valves – 1/8" to 1" Ports (Body, Stacking, Manifold)
- Miniature Control Valves
- Solenoid Valves (DIN)
- Flow Control Valves
- Circuitry Valves – Mechanical, Manual, Solenoid, Pilot Valves



Circle 461

Pneumatic Cylinders

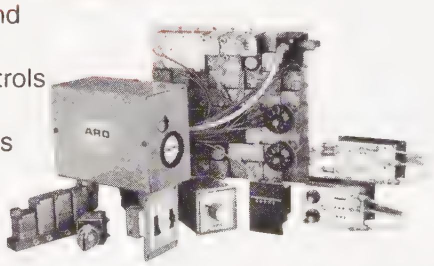
- Square Head Cylinders – 1-1/2" to 8"
- Round Line Cylinders – Repairable and Non-Repairable – 1/2" to 4" Bore
- Air/Hydraulic Cylinders
- Clamping Cylinders



Circle 462

Pneumatic Logic

- Control Elements and Interface Devices
- Panel-mounted controls
- Indicators
- Counters and Timers
- Sensing Devices
- Enclosures



Circle 463

Air Systems Components

- Air Line Filters, Regulators, Lubricators. Conventional and modular – 1/8" 1-1/2" Port Sizes
- Couplers-Connectors
- Blow Guns
- Balancers
- Coil Hose
- Safety Air-fuse Valves

Circle 464

ONE ARO CENTER,BRYAN OHIO 43506 • 419/636-4242 is the numerator of a fraction listed in 16ths of an inch. For example, — 12 tubing has a 12⁄16-in. OD. Hose sizes are similarly designated, except that the dash number refers to ID rather than OD.

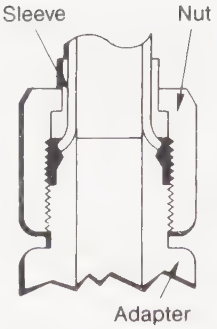
Wall thicknesses of metal tubing can be calculated from the equation given earlier. Use the safety factor of 4 for aircraft and missiles and for industrial, stationary, noncritical applications with minimal shock and abuse; 6 for average industrial applications with normal vibrations and impulse shock; 8 for JIC standard applications and for systems exposed to severe hydraulic and mechanical shock and abuse.

Tube fittings

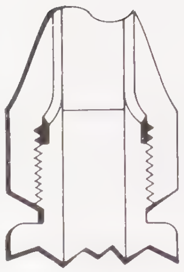
Temperature and pressure decide which type of tube fitting is needed. Metal fittings are used for high temperature and pressures, plastic fittings for low. Typically, metal fittings are used with metal tubes, but plastic fittings are sometimes used with metal tubes to reduce galvanic corrosion.

The fittings used on hydraulic tubing for high-pressure applications are categorized as either permanent or separable. Most separable fittings are threaded.

Threaded flare fittings press the flared end of the tubing against the mating surface of the fitting. As the fitting pieces are drawn up tight, a conical seal is formed.



THREE-PIECE 37° FLARE FITTING



TWO-PIECE 45° FLARE FITTING

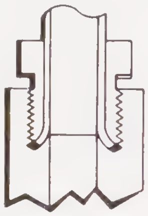
Two flare configurations are standard with the Society of Automotive Engineers (SAE). The 45° flare is used extensively in nonhydraulic automotive, refrigerant, and marine systems. The 37° flare (formerly known as the JIC flare) is extensively used in hydraulic applications. The 45° fittings are commonly made of brass, but 37° fittings are commercially available in brass, steel, and stainless steel.

Several types of flare fittings are available. Two-piece fittings place pressure against the flare with a long-necked nut that aligns and supports the tubing. Application of tightening torque tends to twist the tubing. Friction between nut and flare may produce unequal distribution of the compression force on the flare. The long-necked nut requires its full length of tubing before a bend can start.

A three-piece fitting (nut and sleeve) creates tightening force with a short nut which is transmitted by a sleeve to the flared tube. No twisting action is transmitted to the flare and, because the nut is short, tubing bends can be placed closer to the fitting.

The 60° cone fittings seal by metal-to-metal contact, with a tapered cone seating onto the tube (or nose in the hose swivel) in the most widely used version. The fittings exhibit good sealing reliability, but are highly torque sensitive in small sizes.

O-ring face-seal fittings compress an O-ring against a flat face, providing a positive, leak-free seal. They provide near-instantaneous torque rise when the connection is tight, ensuring proper installation. And once hand tight, they require less rotation to seal properly, making them suitable for plumbing in tight spaces. O-ring materials must be compatible with the sealed fluid.



INVERTED-FLARE 42° FITTING

Inverted flare fittings have a 42° flare on the inside of the fitting body. Inverted flare fittings are used primarily in automotive applications.

Threaded self-flaring fittings do not require a special flaring operation.

Tube and hose connections

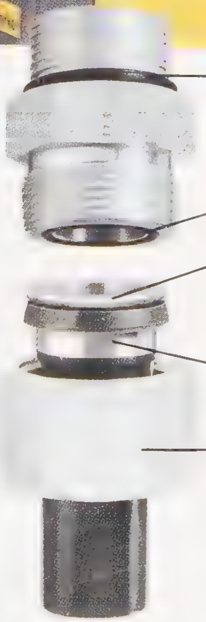
Type of port	Threads	Method of sealing	Sealing reliability	Tube preparation	Pressure rating (psi)	Current users
37° flare SAE J514 (ISO 8434)	UN & UNF (ANSI B1.1) (ISO 263)	Metal to metal	Good	Flaring	1,750 to 5,000	Most popular fitting in the world. Widely used in U.S. & Canada. Moderate use in Europe. Some use in rest of the world.
60° cone JIS B8363	BSPP JIS B0202 (ISO 228) Metric fine JIS B0207 (ISO 261)	Metal to metal	Good	Flaring	1,500 to 5,000	Mainly used in Japan and U.K.
24° cone flareless DIN 2353 (ISO 8434)	Metric fine (ISO 261)	Metal to metal and elastomer	Very good to excellent	None with small sizes, ferrule presetting with larger sizes.	3,500 to 9,000	Second most popular fitting in the world. Widely used in Europe & Japan. Some use in rest of the world.
24° cone flareless SAE J514	UN & UNF (ANSI B1.1) (ISO 263)	Metal to metal	Very good	None with small sizes, ferrule presetting with larger sizes.	1,750 to 5,000	Mainly used in U.S. & Canada.
O-ring face seal SAE J1453	UN & UNF (ANSI B1.1) (ISO 263)	Elastomer	Excellent	Sleeve brazing or tube flanging	3,000 to 6,000	Mainly used in U.S. & Canada. Gaining use in rest of the world.

Now you can flange hydraulic tubing for leak-free Parker Seal-Lok™ connections in less than a minute, without welding or brazing.

The Parker Parflange/Seal-Lok System:

In less than a minute you can flange hydraulic tubing for Parker Seal-Lok ORFS connections up to 1-1/2″ with the new Parflange* hydraulic flanging machine. Parker Parflange will save you considerable time and money by eliminating the need for expensive, time-consuming welding or brazing. The exclusive orbital spindle motion produces a reliable flange with smooth mating-surface. The result is a perfect flange, every time. And, when joined with Parker's Seal-Lok fittings, you'll get leak-free connections up to 6000 PSI.

For details on Parflange, and Parker's complete lines of *Seal-Lok, Triple-Lok, Ferulok* and metric tube fittings *Call toll-free 1-800-C-PARKER.* Tube Fittings Division, Parker Hannifin Corporation.



Seal-Lok Body Over twenty shapes available, forged from steel with rolled (not cut) straight threads for added strength and reliability.

Captive, high-durometer O-ring seal.

Flanged Tube End Exclusive Parflange orbital spindle motion produces a reliable flange with smoother mating-surface for positive sealing.

Parflange Sleeve Specially-designed profile ensures maximum tube support.

Seal-Lok Nut Cold formed for high impact strength and resistance to mechanical shock and vibration.

Seal-Lok Fittings Meet or exceed SAE J1453 performance requirements.

* Patent Pending
Seal-Lok, Triple-Lok and Ferulok are trademarks of Parker Hannifin Corporation.

The World Standard

Parker
FluidConnectors

TF-139

Port comparison

Type of port	Threads	Method of sealing	Seal availability	Sealing reliability	Dynamic pressure rating (psi)
SAE straight-thread O-ring port (SAE J1926)	UN & UNF (ANSI B1.1) (ISO 263)	O-ring in conical cavity	Excellent world wide; SAE J515	Excellent	3000 to 6000
ISO 6149 (DIN 3852, form W)	Metric (ISO 261)	O-ring in conical cavity	Good in W. Germany; poor in rest of world	Excellent	3000 to 6000
BSPP (DIN 3852 — part 2, form X)	BSPP (BS2779) (ISO 228)	a)O-ring with retaining ring b)Metal elastomer bonded seal c)Cutting face d)Soft metal seal	Very good in Europe; limited elsewhere	Good to excellent Fair to good Fair to good Poor	Considered comparable to SAE J1926
DIN 3852 type 1 form X & Y	Metric (ISO 261)	a)O-ring with retaining ring b)Trapped seal ring c)Metal/elastomer bonded seal d)Cutting face e)Soft metal seal	Very good in Europe; limited elsewhere	Good to excellent Excellent Fair to good Fair to good Poor	Claimed to be 3500 to 9000
Four-bolt split-flange code 61 & 62 (SAE J518)	UN & UNF. SAE grade 5 bolts	O-ring in flange head	Excellent world wide	Excellent	Code 61: 3000 Code 62: 6000

During nut tightening, a special wedge-shaped sleeve presses against the tubing end to create a flare. The fitting works best on thin-walled tubing, where high torque is not required to produce a flare. This joint is mechanically strong and vibration resistant, with good reusability.

Threaded flareless fittings do not require a flaring operation and are usually used with thick-wall tube. Ferrule type flareless fittings seal by forcing the ferrule or sleeve cutting edge into the tubing wall to create an interference seal. The resulting spring-action mechanical joint offers a leakproof seal and resistance to vibration.

The 24° cone flareless fitting is second only to the 37° flared fitting in popularity, and is the most widely used fitting in Europe. Sometimes called an EO style fitting, the design incorporates a 24° tapered throat on the fitting body, and a nut that drives a ferrule into the tube as it is tightened. Metric threads are specified by DIN 2353 (the SAE J514 version of the 24° cone has UN and UNF threads). Three different series are offered, LL for low-pressure, L for high-pressure, and S for high-pressure, severe-service applications. Sealing is by metal-to-metal contact, but there is a welded option for L and S-series fittings that seal with an O-ring as well. These fittings offer excellent sealing reliability.

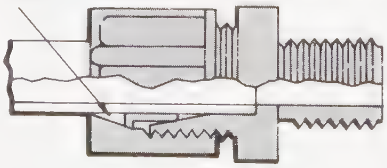
The ferrule-fitting principle is also used in an inverted flareless arrangement, wherein the internal design configuration is machined in the boss part. The tubing is inserted directly into the boss and connected with a male threaded nut which eliminates one seal and permits closer bends.

Compression fittings seal when both ends of the sleeve are compressed during assembly and deflect into the tubing diameter to form two parallel grooves. Since sealing results from nondestructive surface contact between sleeve and tubing, longitudinal defects can affect the seal. Application of this fitting is limited to thin-walled soft tubing, usually copper, and low-pressure vibration-free systems.

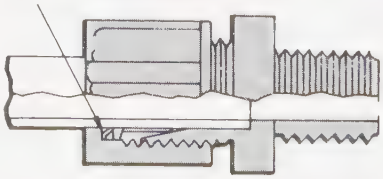
Permanent fittings may be welded, brazed, swaged, or adhesively bonded. These fittings were developed by the aerospace industry, where high reliability, low installation cost, and light weight are prime factors. Though developed for aerospace, many of these fittings are now used in industry. Obviously, they cannot be reused.

Plastic fittings cannot tolerate extreme heat or high pressures. But they cost less than metal, stop galvanic corrosion, deaden noise, and withstand assault by a wide range of corrosive fluids.

PLASTIC GRIPPER



STAINLESS-STEEL GRIPPER



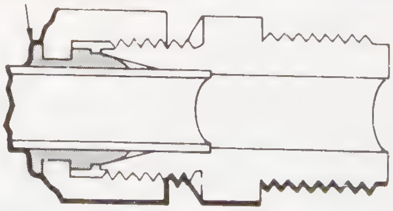
Generally, plastic fittings are well suited to low-temperature fluid-transfer applications. At pressures below 500 psi and temperatures below 250°F, plastic fittings are highly competitive with steel, stainless-steel, or brass fittings.

Plastic fittings have a pullout resistance ranging from 20 to 300 lb, depending on size, tubing material, and locking devices. Plastic or metal grippers are used to increase pullout resistance. Plastic grippers are used only with plastic tubes, and are so strong that the tubing tears before it pulls out of the fitting. Metal grippers are used with metal tubes, and can resist pullout forces over 300 lb.

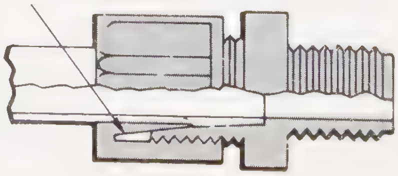
Although plastic fittings are usually used at pressures of 500 psi or less, some fittings have been tested at much higher pressures without failure. With polyethylene tubing, the tubing always fails before the fitting. With nylon, copper, and steel tubing, failure pressures range from 250 to 3,000 psi.

Because plastic fittings are molded

CAPTIVE SLEEVE



INTEGRAL SLEEVE



with smooth internal surfaces, they have inherently low resistance to flow. Furthermore, plastic resists scale buildup and does not rust, so flow passages tend to remain free of obstructions.

Quick-action couplers

Many fluid systems require that hose be disconnected without excessive fluid loss. For these applications, quick-action couplers are used. They are also used to reduce the time, effort, and skill required to make and break fluid connections. Quick-action couplers are available for hoses from ⅛ to 10 in. diameter. They can typically handle 3,000-psi pressures. Some connectors cannot accept pressures this high; a trade-off is necessary to obtain other important operating characteristics.

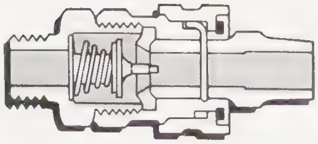
Self-sealing couplers can be used in any part of a system where the pressure-drop rating on the coupler is permissible. They are suitable for vacuums down to 10^{-3} torr. On pump supply lines, a size should be selected that will not produce about 1.5-psi pressure drop at required flow.

A wide variety of seals and materials are available for these couplers: carbon steel, stainless steel, brass, aluminum, many different plastics, bronzes, titanium, and proprietary metals that are inert to most chemicals. Seals are available in Buna N, Neoprene, butyl, Viton, silicone, PTFE fluorocarbon, and natural rubber, plus many proprietary compounds. Selection of the right materials is simplified by the compatibility charts furnished by most coupler manufacturers.

Many types of couplers are available but all have a few factors in common. Each coupler consists of two halves. Either half may contain a leakproof shutoff valve that closes automatically when the halves are separated, and opens when they are connected. The halves are fitted with a locking device for connecting to each other.

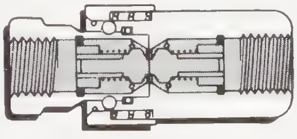
Plain connectors are the simplest and least expensive quick-action coupler. They consist simply of a male nipple and a female coupler, joined usually by a spring-loaded ball-bearing sleeve lock. Typical applications are in laboratory equipment and machine tools, where frequent hydraulic connections are required but spillage is unimportant.

Single-poppet connectors have one plain side and one side automatically closed by a poppet valve. They typically cost about 1.5 times as much as comparably sized and rated plain connectors. In hydraulic circuits they are usually used where lines can be exhausted before disconnection, and as the exit connectors for small portable pumps that spill only a small amount of fluid. Single-poppet connectors are often used in pneumatic circuits, where the poppet closes off the air supply and there is no need to block flow from the actuators.

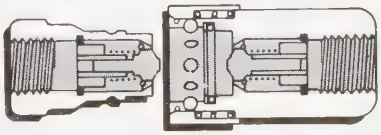


SINGLE-POPPET QUICK DISCONNECT

Double-poppet connectors are the most common type for hydraulic applications. They are typically found on farm equipment, off-road vehicles, and aircraft. The main advantage of the double-poppet connector is that it automatically shuts off flow from both sides of the circuit, allowing only a small volume trapped between the valves to spill when the coupler is disconnected. This feature eliminates the need to drain lines before disconnection, or to provide a means to capture large volumes of spilled oil. However, a double-poppet connector costs about twice as much as a comparable plain connector, has the highest pressure loss of any type, and usually has the lowest pressure rating for a given size. In addition, they are mechanically more complex than plain or single-poppet connectors, and have more potential leakage paths.



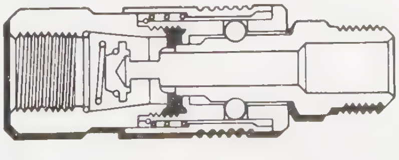
Connected



Disconnected

DOUBLE-POPPET
QUICK DISCONNECT

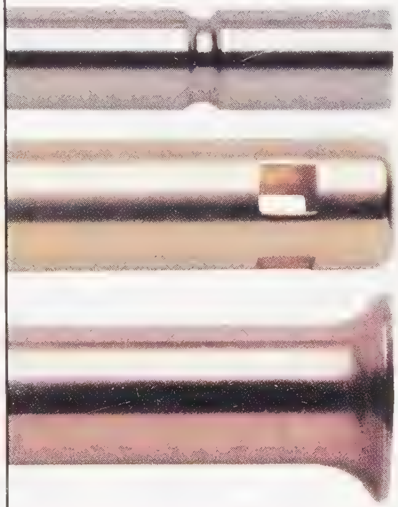
Sleeve and poppet couplers have a self-sealing poppet in one half and a tubular valve-and-sleeve arrangement in the other. There is no space for trapped air. When the coupler halves



SLEEVE & POPPET QUICK DISCONNECT

If You Want This

To Look Like This



Then Dial This

UTI®

1-800-321-6285

There is an almost unlimited parts potential in fine metal tubing . . . and Uniform Tubes is equipped to produce the part that will work for you. Working with over 100 alloys and custom made fabricating equipment, Uniform uses its knowledge, experience, MRP-II and SPC to solve close-tolerance parts problems the world over. Why not yours?

Uniform Tubes, Inc.

Collegeville, PA 19426 · Telephone: 215/539-0700
TWX: 510-660-6107 · Telex: 84-6428 · FAX: 215/489-1150
In Europe: UTI U.K. 983-863338 · Telex: 869441 UTIUK6

Circle 466

NEW!
DESIGNED IN AMERICA, BUILT IN AMERICA

Your ability to compete in the world market just improved.

Meet the Uniport 10K port/fitting system. Its unique metal-to-metal and O-ring double seal is the answer to cost-effective, cleaner, drier, more powerful hydraulics.

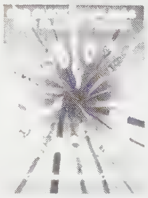
- Unique double seal — zero leakage to 10,000 psi
- 4:1 design factor
- Reduces cost, component inventory and weight

UNIPORT 10K SYSTEM

Call, write or fax for complete information on the capabilities of the Uniport 10-K system.

FLP
Fluid Line Products, Inc.
Designer & Manufacturer of Hydraulic Components
38273 Western Parkway, P.O. Box 1, Willoughby, Ohio 44094
(216) 946-9470 FAX (216) 946-9472

Circle 467



Trial Size!

Thermoplastic Quick Couplings...

Coupling coupon sent with the CPC catalog.

make quality plastic tubing connections. Vacuum or pressure, seal to 120 psi for air, gas or liquid. Hose barb, pipe thread, or ferruless fittings. In-line or panel mounts.

Respond to this ad for a Trial Size Coupling Coupon and our catalog. Select a Delrin coupling for 1/16" to 3/8" tubing – return coupon and $3.00 for shipping. Coupling will be sent promptly.

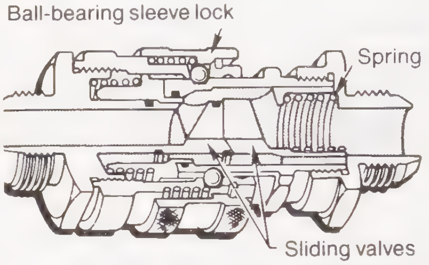
CPC COLDER PRODUCTS CO.
1001 Westgate Drive • St. Paul, MN 55114 • Call 612-645-0091

Circle 468

are disconnected, poppet and sleeve are fully closed before the external seal is closed. No fluid is lost upon disconnection; no air is entrained by the fluid upon connection, so freedom from fluid loss and air inclusion is the most important advantage of this type of coupler.

Double rotating ball couplers use a ball in each coupler half. A passageway through the ball is rotated to permit flow. Air trapped between the balls enters the fluid system. This type of coupler causes only a slight pressure drop but is responsible for significant air inclusion on connection and fluid loss on disconnection. Some users report difficulty in sealing when the couplers are disconnected.

Sliding-seal connectors are generally the Cadillacs of the line. When they are opened, the seals are flush with the ends of the coupler and nipple, so spillage is typically less than 0.12 cc — even for connectors as large as 1 in. diameter. In addition, flush seals leave little space for dirt to collect, and are easily wiped clean. As a result, sliding-seal connectors are almost always used for hazardous or toxic fluids and for other applications where minimum spillage is important. However, these connectors require the highest forces for connection under pressure, and cost about 3.5 times as much as plain connectors.



SLIDING-SEAL QUICK DISCONNECT

Stapled coupler is held together with a barbed staple that eliminates the need for wrenches and other assembly tools. The coupler consists of an outer half with openings that accept the staple, and a mating inner half with grooves. Hoses are connected by pushing the coupler halves together and installing the staple so that it passes through the complete assembly. Barbs at the end of the staple lock the coupler. The coupler can be disconnected by squeezing the staple to disengage the barbs.

Manifolds

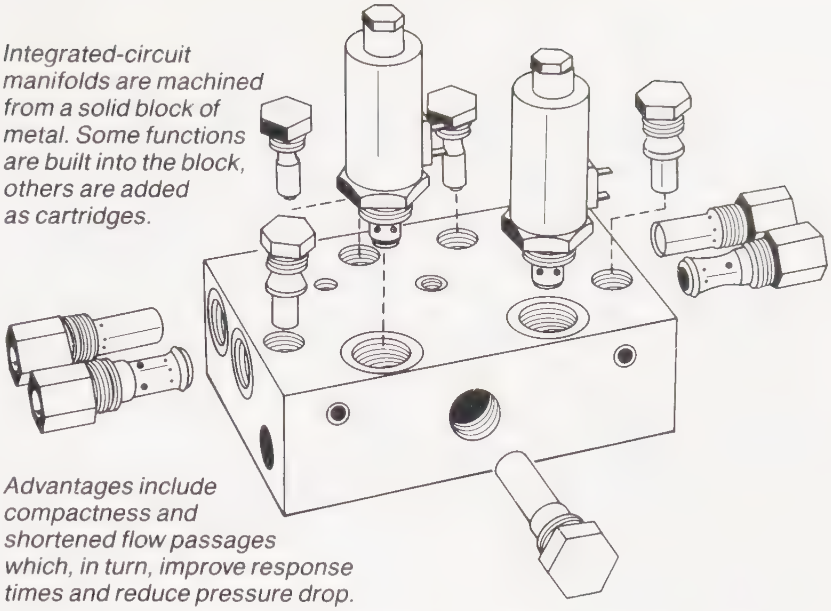
As the number of connections in hydraulic systems increases, so does the likelihood of leaky fittings and of tortuous flow paths that stretch out response time. As a result, hydraulic manifolds are finding greater use in both mobile and industrial systems.

Manifolding drastically reduces the number of external connections required, slashing assembly time and reducing the chance of leakage. But there are other, almost equally important advantages:

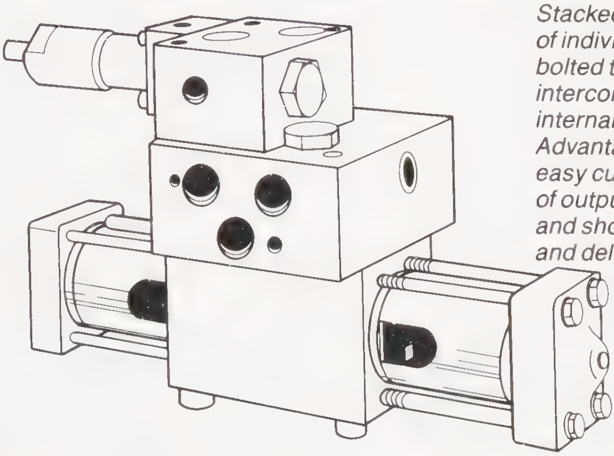
- Space requirements are reduced because many valves are combined in a single package.
- Actuator response time can be reduced — sometimes as much as 50% — because flow paths are shortened and straightened.
- System cost can be reduced because of decreased requirements for tube, hose, and fittings, and because of decreased assembly time.
- Maintenance costs are reduced because valves can be replaced as units.

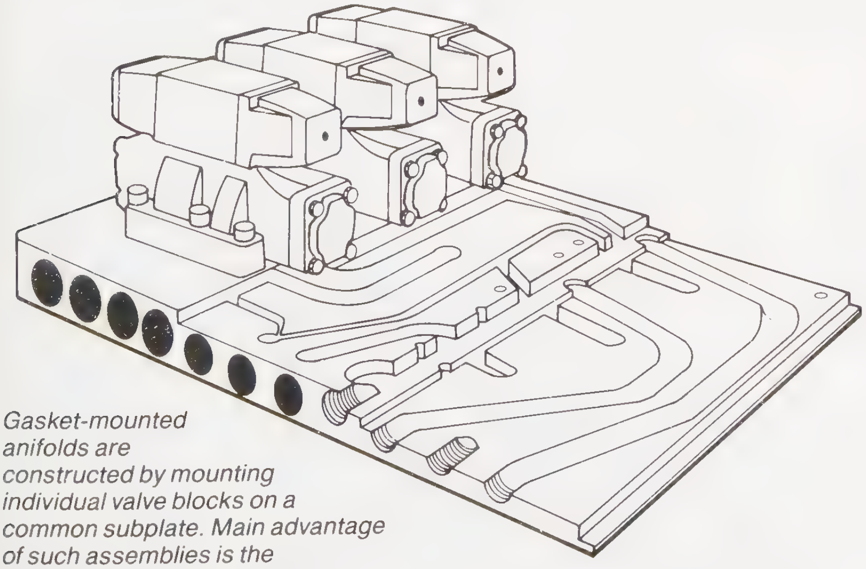
With these advantages come some limitations. Probably the most important is that more design time and testing time are required. Whereas a simple list specifying fittings, tubing, and hose for a system can usually be generated in-house within a day, the design of a manifold block is considerably more complex, usually calling for the services of outside experts. Manifold manufacturers typically require one to three weeks to generate a technical proposal. Fabrication of a prototype may take as little as one week if only standard components are used, but may take considerably longer for special components. And the vital step of prototype testing adds another few weeks.

Manifold design and testing are costly, but the cost must be balanced against reduced system assembly costs. For simple manifolds of three to five valves, the break-even point may be as few as 20 units; few manifolds are so costly that the break-even point is more than 1,000 units.


Integrated-circuit manifolds are machined from a solid block of metal. Some functions are built into the block, others are added as cartridges.

Advantages include compactness and shortened flow passages which, in turn, improve response times and reduce pressure drop.


Stacked manifolds consist of individual valve blocks bolted to one another and interconnected by internal passages. Advantages include easy customization of output functions and short design and delivery times.

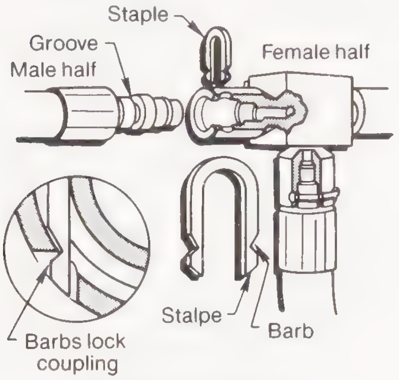

Gasket-mounted anifolds are constructed by mounting individual valve blocks on a common subplate. Main advantage of such assemblies is the elimination of lines and fittings.

Other factors may limit manifold use in some systems:

- Unit-block manifolds, which combine many valves and flow paths in one manifold block, are sensitive to large contaminant particles such as metal chips, pieces of rag, and sealing tape. In some systems, a coarse screen is used at the manifold inlet to filter out these contaminants, but in most cases the pump filter provides adequate protection. In systems without a pump filter, a manifold filter rated at 20 to 25 μm absolute is recommended.
- Because manifolds and valve packages enclose flow paths and place valves close to each other, they tend to produce fluid temperatures somewhat higher than those encountered in conventionally plumbed systems. The higher temperature may affect seal and gasket selection, and may require a larger oil cooler.
- Although valve replacement is easy in both unit-block manifolds and valve packages, fault location is typically more difficult with manifolds than with valve packages or conventional systems. The difficulty arises because flow passages in manifolds are

not easily blocked off to isolate different portions of the circuit.

One way to retain many of the benefits of manifolding while avoiding much of the design time and cost associated with unit-block manifolds is to use valve packages, or "modular manifolds." These packages consist essentially of valves that bolt directly to each other, without intermediate plumbing. One set of lines connects all valves in the package.



STAPLED COUPLING

In addition to directional-control valves, components such as flow dividers, flow regulators, check valves, lock valves, and relief valves are available in modular form. These attachments can be added to a bank of directional-control valves to form packages tailored to specific applications. Because all components are standard units, design effort is minimal. The valve packages are typically furnished without extra assembly charges.

The questions that follow can serve as a quick guide for evaluating the potential benefits of manifolding valves. If half or more of the answers are "yes," chances are good that the use of manifolds will prove cost effective.

- Are valve fittings placed in inaccessible locations?
- Is fluid leakage likely to pose a hazard to personnel or the environment?
- Is space at a premium?
- Is actuator response time significant?
- Is easy valve maintenance important to the system user.
- Are locking or crossover valves needed in association with directional-control valves?
- Is a long production run expected?

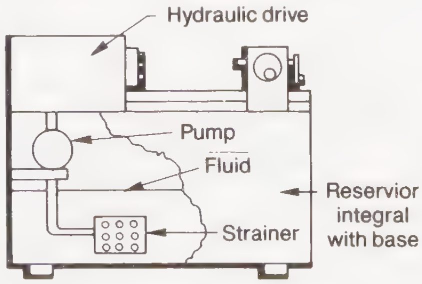
Reservoirs

Many functions in hydraulic systems are provided by reservoirs. First, a reservoir holds the fluid in a convenient spot for the pump inlet. It supples extra fluid to the circulating system in the event of leakage or cylinder extension. In addition, most reservoirs are called upon to perform a fluid-conditioning role, in which the turbulent fluid returning from the hydraulic system is allowed to settle and deaerate. And to complete the complex list, many users expect a reservoir to exchange heat with the outside air, thus cooling the heated fluid.

From these complex and occasionally conflicting requirements have grown a body of folklore about reservoirs. Elegant rules of thumb proclaim that the reservoir should be at least three to five times the size of the per-minute flow; accordingly, a 50-gpm hydraulic system is thought to need at least a 150-gal reservoir. Actually, most of these intricate rules are based on the thought that the reservoir must dissipate much of the system heat. If a heat exchanger is not available, the rules are generally accurate. If a heat exchanger is used, the reservoir can be as small as one time the per-minute flow — or, a 50-gal reservoir for the example system. With astute design of internal baffles and settling areas, the reservoir can be much smaller, perhaps as little as one-half to one-third the flow. And, of course, certain types of closed hydraulic systems require almost no reservoir at all, using instead an external makeup pump to put more fluid into the system as required.

Rules of thumb aside, most applications require a standard industrial reservoir that performs the standard gamut of tasks. In general, the reservoirs can be categorized as integral, dual purpose, or separate.

Integral reservoirs are those built into the structural members of the hydraulic system or machine. For example, space within a machine base can often be made fluid tight at little extra cost, or tubular structural members in a machine can be used as reservoirs, thus eliminating the need for extra additional space.



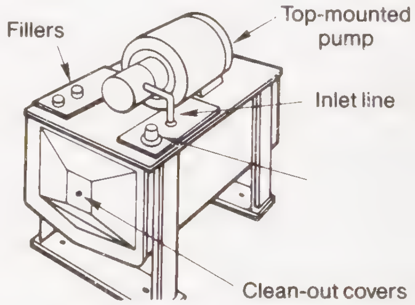
INTERGRAL RESERVOIR

Integral reservoirs offer maximum performance in minimum space and usually provide an excellent cosmetic appearance. They must be designed carefully to surmount possible operating problems such as localized heating and poor accessibility.

For example, localized heating of a machine base by high-temperature hydraulic fluid can cause thermal distortions that produce machine inaccuracies. Accessibility for cleaning of the reservoir and servicing intake filters may be difficult or even impossible.

Dual-purpose reservoirs are those in which a common reservoir is used for hydraulic fluid and lubricating fluid. For example, a tractor-transmission case is also used as the reservoir for the tractor hydraulic system. Primary benefit is the space saved.

Offsetting this are several limitations. The fluid must meet the requirements of both the hydraulic system and the transmission gears. In some high-performance systems, these requirements may be almost mutually exclusive. In addition, temperature control of the fluid may be difficult because there are two sources of heat for the reduced total amount of fluid. If a separate heat exchanger must be added, space required tends to offset the saving.



SEPARATE RESERVOIR

Separate reservoirs are most commonly used for industrial jobs. They may be rectangular (with pump and motor mounted on the top), vertical, or L-shaped. With a rectangular system, the pump inlet line is short and can be opened without difficulty for servicing. The inlet filter is readily accessible. A vertically mounted motor and pump can be combined to reduce space requirements. The drive motor extends above the tank top, and the pump is supported on the underside of the top. Although this arrangement protects the pump and keeps lift requirements to a minimum, maximum size of the system is limited. The motor pump cover and any attached controls must be removed as a unit for servicing the reservoir.

L-shaped packages have a tall, narrow rectangular tank with pump and motor mounted beside the tank on a common base. The pump suction line enters the tank through the side, either below or above the fluid level. If the line enters below the fluid level, the reservoir fluid provides a positive feed to the pump; however, a shutoff valve must be included to permit servicing the pump without draining the tank.

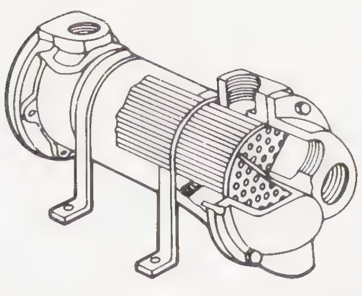
A rectangular tank placed above the pump and motor, in an overhead configuration, again provides positive inlet pressure for the pump and permits easy tank access for servicing. However, access for pump service is limited, and a shutoff valve must be included to permit servicing the pump without draining the reservoir.

As mentioned earlier, the traditional rules of thumb for determining reservoir size are inadequate. The only accurate method is to determine the heat balance of the hydraulic system, calculate the amount of heat that will be generated in it through lost work, then determine the amount of space available and the amount of heat that can be dissipated in that amount of reservoir space. Such a calculation will quickly reveal the necessity for a heat exchanger, if it exists. After a decision is made on a heat exchanger, the reservoir size can be determined. Whatever the size and type of reservoir used, experts recommend that extra features be included.

Heat exchangers

Unwanted heat is a problem for all hydraulic systems. Even a well-designed system operating at top efficiency converts about 20% of its input power to heat. An inefficient system, or one poorly matched to its task, may convert nearly 100% of input power to heat at certain times in the cycle. The heat input can be dissipated through natural cooling; if this is insufficient, a heat exchanger is added to the system.

Liquid-to-liquid exchangers draw heat from the hydraulic fluid and transmit it into a cooling fluid, usually water. Most liquid-to-liquid exchangers use a shell-and-tube package, consisting of a bundle of small tubes inserted into a shell. The coolant flows through the small tubes, and the hydraulic fluid passes around and between the tubes. These units are compact, reliable, and are often less expensive to install and maintain than other types.


LIQUID-TO-LIQUID HEAT EXCHANGER

There are two basic types of shell-and-tube exchangers: the U-tube (or hairpin) type and the straight-tube type. Either type can have either a fixed or removable tube bundle. Removable bundles can be withdrawn from the shell as an assembly for maintenance, but fixed bundles must remain in the shell. A normal rule of thumb is that U-tube exchangers are best suited for high-temperature, high-pressure applications, with the straight-tube units most thermally efficient and least expensive.

Liquid-to-liquid exchangers are available in single or multiple-pass, parallel, or reverse-flow arrangements. The multiple-pass, reverse-flow units provide the greatest heat transfer for a given size. Standard liquid-to-liquid units have a working pressure of 150 psi and can handle temperatures to 300°F, although the actual temperature difference between oil and water should not exceed 200°F. Special units are available to operate at pressures to 300 psi.

With Legris...you always get the perfect solution

Full selection of push-in fittings meet the demands of any application

Since we first invented the push-in fitting, the Legris product line has evolved to address practically every conceivable use.

Legris full flow elbows are a good example, with bodies of nylon, brass or stainless steel. Configurations of standard, low-profile, banjo, orientable and oscillating. Tapered or straight threads from 1/8″ to 1/2″ NPT, 10/32, M3, M5, and 1/8″ to 1/2″ BSP. Tubing sizes from 1/8″ to 1/2″ or 3mm to 14mm, accepting nylon, polyethylene, polyurethane or teflon tubing.

We're pretty confident that we have the exact elbow, or for that matter, any other fitting you might need. In fact, you're probably just a phone call away from the perfect fitting solution.

A great fitting solution: another reason Legris push-in fittings are the most popular in the world, with more than half a billion in use.

For more information on Legris push-in fittings, call or write today.

legris
INCORPORATED

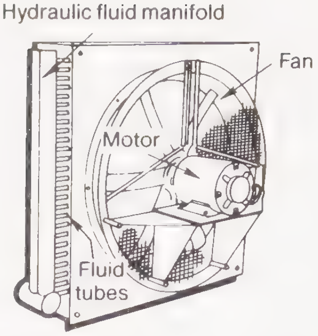
244 Paul Road
Rochester, New York 14624
Telephone (716) 328-6250

In Calif. (714) 588-1018
In Canada (416) 670-9422
In Carolina (803) 675-1176
In Illinois (708) 543-0986
In Texas (214) 437-9379

GROUPE LEGRIS INDUSTRIES

© Legris Incorporated, 1992

Circle 469



LIQUID-TO-AIR HEAT EXCHANGER

Liquid-to-air heat exchangers transfer heat from hydraulic fluid to ambient air. Working much like an automobile radiator, they allow air to be passed over finned tubes containing the hot liquid. The finned tubes can be made of aluminum, copper, steel, or stainless steel, and are brazed or roller expanded to the header tank. Air is moved through the core by forced or induced-draft fans.

Air-cooled exchangers are most commonly used where water is costly or unavailable in sufficient quantities to dissipate the required heat, or where a portable heat exchanger is required. In some instances, they have been used to help supply plant heating requirements during winter months. These liquid-to-air heat exchangers are available in sizes to 100 hp, operating at pressures to 300 psi. Units up to 600 hp are available on special order.

Typically, liquid-to-air exchangers are larger, heavier, and noisier than liquid-to-liquid units. In return, they operate without necessity for water and they are portable. They require ambient air at least 10 to 15°F below the required oil output temperature for efficient operation. The only requirement for long life is that fins must be protected from clogging and dirty environments; a single mesh (window screen) overlay avoids fin clogging and provides for easy cleaning.

The heat pipe is a high-performance thermal conductor. In its basic form, it consists of an enclosure containing a fluid that can be vaporized and a material or structure, called a wick, that provides capillary action. In an essentially isothermal process, heat at the input, or evaporator, end causes the fluid to evaporate. Vapor travels through the center of the container to the output, or condenser, end. There the vapor condenses, giving up its latent heat, returns to a fluid state, and travels back to the evaporator end through the wick.

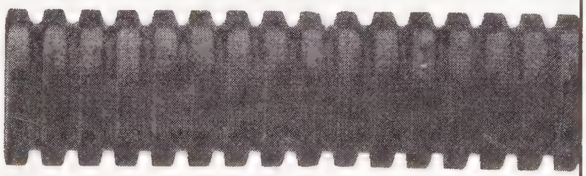
Although called heat pipes, not all of these devices are cylindrical. Tubular heat pipes predominate because most are fabricated from stock tubing materials. Any geometry that preserves the essential evaporation-condensation cycle can be used. Flat heat pipes are being made, and flexible heat pipes are used where the evaporator and condenser cannot be in line or where both heat-pipe ends oscillate independently.

Pipe materials are usually metal, such as copper or aluminum, but for some electrical applications they can be made from a dielectric material.

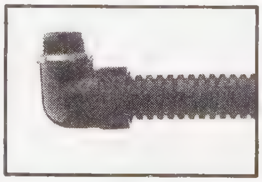
Working fluid depends on the temperature range over which the heat pipe is to operate, and the amount of heat to be moved. For cryogenic applications, hydrogen, which operates between −259 and −248°C, may be used. For high temperatures, sodium, lithium, and silver may be the working fluids. Sodium, for example, functions in the 550 to 1,000°C range. Most commonly used tubes operated in the 0 to 500°C range using water, one of the Freons, or a variety of organic fluids such as Dowtherm A.

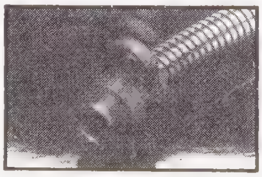
The wicking material or structure performs two functions: channeling liquid through the tube, and wetting the tube interior. The wick design used depends on the working fluid, the tube orientation and desired heat flow. Slits or spirals, cut or formed into the tube

THE CORRLOK® SYSTEM...



100% NYLON CORRUGATED
FLEXIBLE ELECTRICAL CONDUIT
and CONNECTORS





These Injection-molded Nylon 6 connectors complete the ideal liquidtight system, when used with Corrlok conduit from Electri-Flex. Features a unique fixing clip assembly which preserves liquidtight integrity, while permitting full swivel for easy installation and hook-up.

Variety of trade sizes, in both straight and 90° configurations with NPT threads standard. Bulkhead connectors also in stock. Metric and PG threads available on request.

FREE CATALOG

electri-flex
ELECTRI-FLEX COMPANY
222 West Central Avenue
Roselle, IL 60172-1994 (708) 529-2920
Manufacturers of liquatite® Flexible Conduit

Circle 470

EXTREME
TEMPERATURE
RANGE

TYPE ATX
Liquatite® Flexible Conduit

This *new* liquidtight steel conduit is designed for use in extreme temperature conditions. The extruded thermoplastic rubber jacket will remain flexible from −75°F to +300°F. The halogen-free jacket material has a flammability rating of UL94HB. and has excellent resistance to most oils/acids/alkalines/ozone.

Free sample on request.

electri-flex
ELECTRI-FLEX COMPANY
222 West Central Ave., Roselle, IL 60172
(708) 529-2920
Manufacturers of liquatite® Flexible Conduit

Circle 471

wall may be sufficient in some cases. Sometimes, special wicking material, such as sintered metal, mesh, or various types of cloth, are necessary.

Location: All heat exchangers should be installed in the low-pressure side of a hydraulic circuit. This location eliminates the need for a high-pressure unit, which may be comparatively expensive. Heat exchangers should be protected against damage from high-pressure surges by a relief valve.

For large hydraulic systems operating at high pressures, a separate cooling circuit from a reservoir to the heat exchanger may be used to circulate the oil independent of changing flows in the main circuit.

For systems that are to be used outside, a system bypass line should be provided around the heat exchanger. Such a bypass line permits efficient year-round operation; the heat exchanger can be bypassed during cold weather starting until fluid has reached the operating temperature. Such a bypass line also permits maintenance of the heat exchanger without shutdown of the hydraulic system.

Experts recommend that line filters be installed upstream of the unit to protect the exchanger from excessive accumulations of dirt and scale, which can degrade thermal efficiency.

Protection: Generally, the colder the chilling fluid (air or water), the more heat will be removed from the oil — up to a point. At temperatures below a certain level, the fluid may be too cold for efficient operation of the exchanger. Most hydraulic fluids tend to form viscous layers on contact with an extremely cold surface, and this stagnant fluid can create a thermal barrier within the heat exchanger. The colder the chilling fluid, the thicker is the viscous layer in the hydraulic fluid. For example, a 1-in. layer of noncirculating fluid has the insulating quality of a ¼-in.-thick layer of rock-wool insulation. Therefore, the heat-transfer capability of an exchanger under cold-weather operation may be improved by restricting the temperature or supply of the chilling fluid.

Clean, soft water should be used in water-type heat exchangers to prevent corrosion and scaling in the tube bundle. If the only available water is hard (with excessive minerals) or brackish (with excessive salt), scale and dirt deposits can form in the small-diameter tubes. These deposits cut heat efficiency. Where fouling is possible, low cooling-fluid velocities should be avoided.

Another potential hazard to cooling efficiency is tube corrosion. Corrosion restricts coolant flow and can eventually perforate the tubes, permitting water to pollute the hydraulic fluid. Experts recommend use of a zinc anode or chemical inhibitor in the cooling water circuit to prevent or reduce this deterioration in the tube bundle.

Doubling up: If the flow requirements of the hydraulic system exceed the capacity of standard heat exchangers, two smaller standard units of equal capacity can be connected in parallel to dissipate the heating load. In this arrangement, the thermal load is shared equally by each small exchanger at a total system cost much less than a single large unit custom built for a system.

Many hydraulic circuits generate high thermal loads for relatively short periods. During normal operation, normal loads can be carried away by a standard liquid-air exchanger but, under extreme operating conditions, a small liquid-to-liquid unit is required to carry the additional load. In such circuits, the liquid-to-liquid exchanger is installed in series with, but downstream of, the liquid-to-air unit. With a bypass line around it, the water-type exchanger is held in standby during normal system operation. Again, this "ganged" arrangement is simpler and more efficient than use of a single, very large exchanger capable of handling peak loads.

Flow sensors

Recent advances in flow sensing have resulted in more accurate, durable, and economical meters. Increasingly important is the ability to interface meters with a computer for instantaneous flow readout to remotely control flow, or to allow unattended process operation. To meet such demands, new types of flowmeters are being introduced, and older designs are being improved and updated.

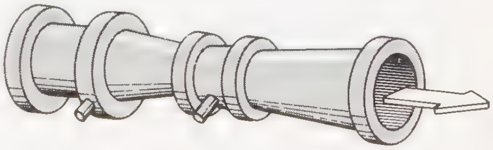
Prime considerations when selecting a flow sensor include: the type of fluid being measured, its temperature and pressure, viscosity, conductivity, corrosiveness, and cleanliness. Equally important are the requirements of the sensor itself: Flow velocity range, accuracy, ease of installation, and maintenance requirements. Finally, cost can be a major factor in the decision.

Two basic classes of flowmeters are differential producers and linear flowmeters. Differential-producer flowmeters create a restriction in the flow field. When flow is contracted, either gradually or abruptly, kinetic energy increases at the expense of potential energy (static pressure). The difference between pressure at the full pipe section and that in the vicinity of the contraction is related to the square root of the velocity at the full section minus the square root of the velocity at the contraction. Fluid properties and the abruptness of the contraction also play a role in the operation of these meters. General range is 4:1.

The pressure/flow relationship depends on the length and condition of the reference piping, pressure tap locations, and the geometry of the restricting element (differential producer). Any change in these characteristics alters the relationship, making these devices extremely sensitive to installation conditions. The greatest disadvantage to this class of flowmeters is that they require a secondary measuring system — flow is determined based on a pressure-flow relationship.

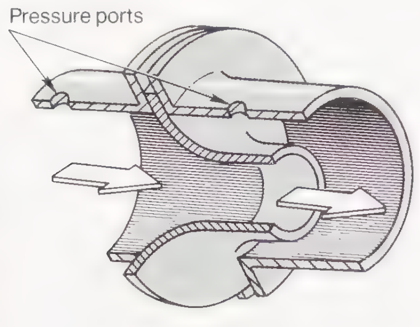
Orifice-plate flow sensors are the most widely used of the differential pressure flow sensors; others being nozzle, venturi, and flow tube. Generally, an orifice sensor is a circular plate inserted between flanges of a pipe with a round or other shape hole bored in the plate center, matching system flow range and characteristics. Pressure taps on each side of the orifice plate measure the pressure differential, and a transmitter produces a signal that is proportional to the square of flow rate. Because the relationship between flow and pressure involves a square root, the differential drops off quickly as flow decreases. For this reason, the dynamic range for these sensors is limited to about 4:1. Accuracy also varies with flow rate, from 1 to 3%.

Venturi tubes produce differential pressure through a section of pipe with a tapered inlet and diverging outlet. The contoured surfaces allow measurement of dirty gas and liquid. Line sizes are typically 2 in. and larger, and accuracy ±1 to 2%. However, the devices are costly.



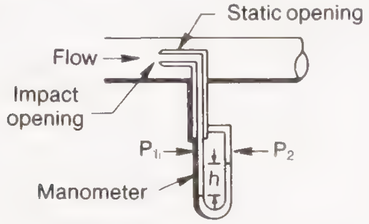
VENTURI TUBE

Flow nozzles are generally used in steam/vapor flows at high velocities. Differential pressure is produced by a pipe section with an elliptical entrance and nozzle exit. In general, line sizes are 2 in. greater, and accuracy is ±1 to 2%. Flow nozzles are expensive and may cause permanent pressure loss.



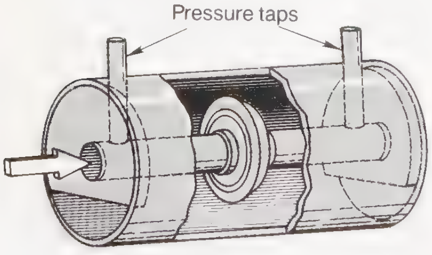
FLOW NOZZLE

Pitot tubes provide basic flow measurement for laboratory tasks. A pitot tube consists of a special tube facing into the flow to measure a velocity-augmented impact pressure and a second tube that measures static pressure. Difference between the two pressures is normally measured on a U-tube manometer. A pitot tube measures velocity at only one point in the fluid stream. Accordingly, the sensor must be moved around in the stream so that a variety of readings can be taken to yield a velocity profile.



PITOT TUBE

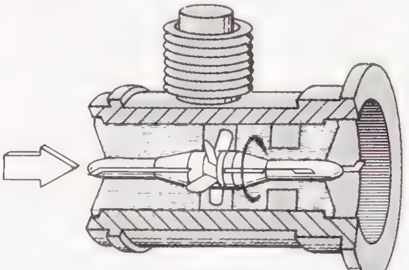
The annular orifice, consisting of a disk supported concentrically in a pipe section, was developed to overcome the problem of dirt buildup in front of a standard orifice. Operating principle is the same as with a standard orifice meter. It works with both clean or dirty gases and liquids, generally 4 in. and larger line sizes; accuracy is ± 2%.



ANNULAR ORIFICE

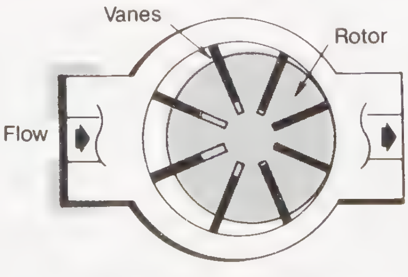
Volumetric flowmeters whose output is not proportional to the square root function are termed linear flowmeters. Meters are either linear due to the principle of operation or linearized through electronic means. Typical range of this class of flowmeters is 10:1.

Turbine flowmeters use a turbine, positioned in a tube, which rotates with passing fluid flow. A proximity sensor detects turbine blade movement and generates a frequency signal that is analogous to flow rate. These sensors are compatible with a variety of fluids, and provide a wide flow range. The dynamic range or turndown ratio (that is, the ratio of maximum to minimum flow rates) is up to 35:1 in some turbine flow sensors. Accuracy over this range is generally about 1%, and response is linear over the entire range, simplifying electronics. Pressure drop across the turbine is quite low (generally about 20 psi at maximum flow), which is an advantage turbine sensors hold over some other types.



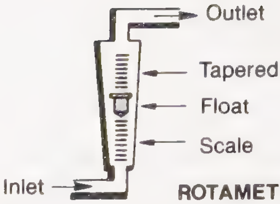
TURBINE

Positive-displacement meters offer the ultimate in volumetric accuracy, but require maximum interference with the flow stream. Basically, they function like a hydraulic or pneumatic motor, with the "output shaft" of the motorlike device driving the gage readout. Because these meters are very similar to the hydraulic and pneumatic motors used in fluid-power applications, they are suitable for extremely high pressures. A big advantage of positive-displacement types is their ability to discern extremely low flow, down to a few cc per minute. They are also highly accurate (typically 0.5 to 1% of flow rate), have a dynamic range up to 400:1, and are bidirectional. Hydraulic pulsation has no effect on these sensors, and they can be placed almost anywhere in the system.



POSITIVE-DISPLACEMENT METER

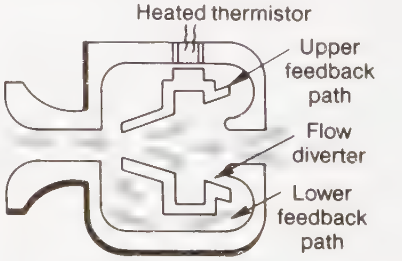
Rotameters are the most common variable-area meters, consisting of a tapered tube in which a float is supported by the fluid flowing up through the tube. As the fluid flow increases, the float is lifted higher in the tapered tube, as greater orifice area is required around the float to transmit the flowing fluid. The reading is taken directly from the float position. Rotameters are typically used for low-pressure flow readings; they are most suitable when used for a single fluid.



ROTAMETER

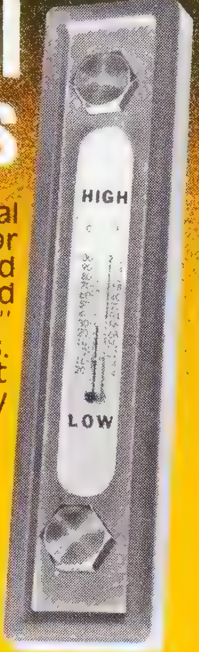
Vortex-shedding sensors detect flow from viscosity-related effects of a blunt object in a flow stream. Basically, when fluid flows around an object, vortices are shed alternately from one side of the object, and then the other, in a regular pattern. Sensing the rate of vortex passage gives a measure of flow velocity. A number of methods have been developed to detect vortex passage. One is a piezoelectric crystal element that senses induced strain in the shedder bar; another is diaphragm pressure sensors located just beyond the shedder bar. Both have good dynamic range (20:1) and excellent accuracy (0.8%).

Fluid-oscillator meters are based on the Coanda effect, in which a fluid jet adheres to the walls of a Venturi nozzle. When the jet attaches itself to the lower wall, it encounters a flow diverter that splits the flow toward the upper wall. At the upper wall, it encounters a second flow diverter that splits flow back to the lower wall. Flow oscillation is a linear function of flow rate. A heated thermistor placed in the upper feedback passage measures oscillation rate, and hence flow.



FLUID-OSCILLATOR METER

Jet-deflection meters use measured flow to detect a high-speed jet from receiving ports. Flow is proportional to the amount of deflection. In some models, the nozzle and port assembly can be moved to obtain a complete velocity-profile distribution curve.



Lower installation costs

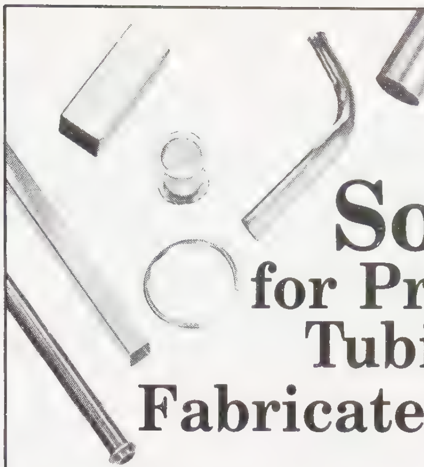
Flush-mounted Oil Level Gauges

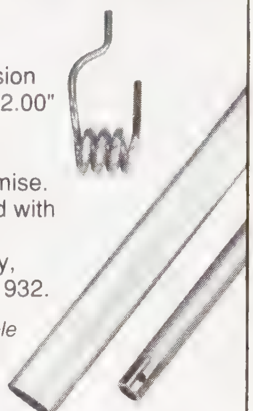
Provide instant visual check on oil levels for every commonly used reservoir. Five standard sizes with 2³/₈", 4", 6", 8" and 12" long sights. Available with or without thermometer. Completely assembled, including gaskets and fasteners. Easily installed. Only two small holes to be drilled in the reservoir.

Send for complete product brochure and price sheet. Or, call us (607) 732-6620.

Federal Brass
Manufacturing Company, Inc
165 Cedar Street • Corning, NY 14830

Circle 472





The One Source for Precision Tubing and Fabricated Parts

- 22 Non-Ferrous Alloys.
- Fabricated components and precision drawn tubing…OD's from .010" to 2.00" and walls from .003".
- Tight tolerances to meet the most critical standards, without compromise.
- Problem solving designs combined with advanced technology.
- Single source reliability with quality, performance and economy since 1932.

Tubing/Parts Reference Guide Available

PRECISION TUBE COMPANY INC.
North Wales, PA 19454
Tel.: (215)699-5801
Fax: (215)699-0761

Circle 473

Plastic tubing from plastic tubing specialists.

Call NewAge today and tap into a single source for plastic tubing and hose. Your call will be answered by a tubing specialist who's ready to discuss your application and offer engineering assistance.

Need samples and specs? He'll put them in the mail the same day.

Know what you want and need it in a hurry? Chances are it can be shipped from NewAge stock within 24 hours.

And if the compound, size or configuration is so special that *nobody* stocks it—NewAge can supply that too.

NewAge also stocks the other things you'll need: couplings, fittings, connectors and clamps. So whatever you need in tubing and hose, call a NewAge specialist today . . . and get the answers from a single source.

NEWAGE INDUSTRIES
2300 Maryland Rd.
Willow Grove, PA 19090
(215) 657-3151

Circle 474

Lower installation costs.

Filler-Strainer Assemblies

Six styles available for hydraulic or lube oil reservoirs. Offered in both conventional cover-mounting and our unique side-mounting design. Furnished completely and assembled with internal safety chains, gaskets and fasteners for immediate installation.

Send for complete brochure and price sheet. Or, call us (607) 732-6620.

Federal Brass
Manufacturing Company, Inc
165 Cedar Street • Corning, NY 14830

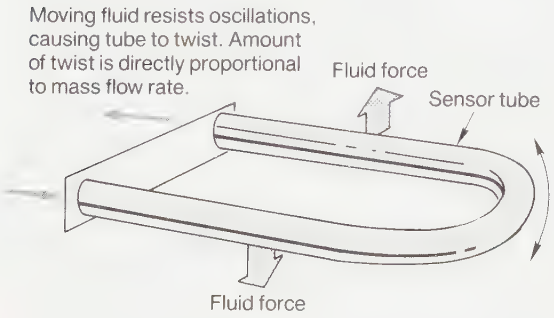
Circle 475

MEASURING ULTRALOW FLOW

Accurate flow measurement and control at low and ultralow rates is difficult compared to higher flow regimes. Because the meters deal with relatively small volumes of fluid, minute measurement errors greatly affect accuracy. Further, conventional meters cannot simply be downsized, because many metering methods common in the moderate-to-high flow range do not work at the low end.

To overcome these problems, specialized measurement techniques have been developed, ranging from well known to the unusual and clever.

CORIOLIS



Moving fluid resists oscillations, causing tube to twist. Amount of twist is directly proportional to mass flow rate.

Sensor tube vibrated at its natural frequency by an electromagnetic drive. Typical amplitude is less than 1 mm; frequency about 80 Hz.

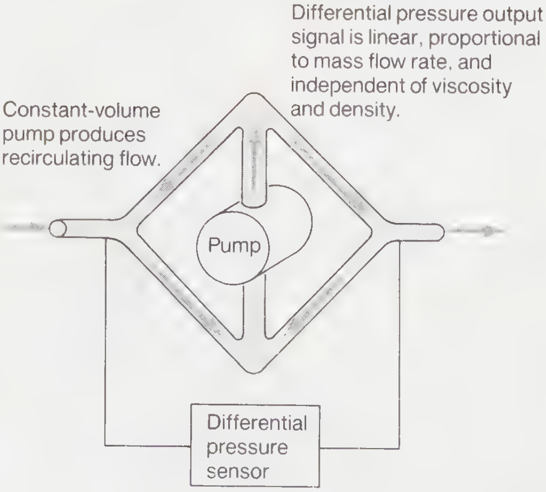
Coriolis flow meters consist of a U-shaped tube (or pair of tubes) through which fluid flows. The U-tube vibrates in a direction normal to the plane of the tube. As fluid passes through the vibrating curved segment of the tube, it produces a reaction tending to twist the tube. Angle of twist is a measure of the fluid's mass flow rate; fluid density can be measured simultaneously. Coriolis meters tend to have relatively high-pressure drop. They are quite versatile and many competitors have recently entered the market. Each has his own variation: spiral tubes, S-shaped tubes, parallel tubes, and so on. However, not all such meters will measure low flow. ■

Variable-area flow meters, in various forms, have been used for many years to measure flow of both liquids and gases. One common type is the glass-tube rotameter. These meters generally have low-pressure drop, are inexpensive, and give direct readout, which makes them preferred for many low-viscosity applications. They are also easy to install and use.

One variation is a rotameter-type instrument with electrical output — the bobbin being attached to the core of a differential transformer. It can handle flow rates down to 0.001 gpm or 0.003 scfm at pressures as high as 5,000 psig. Accuracy is 0.5% of full scale.

Fixed-area meters — orifices, nozzles, and venturis — are common flow measurement devices for all flow ranges. A variation of the orifice meter is the hydraulic wheatstone bridge. This meter can measure accurately down to 0.00025 gpm while operating over a range of as much as 1,400:1. Output signal is linear and directly proportional to mass flow rate. Although capable of measuring very small rates, orifices are comparatively large.

HYDRAULIC WHEATSTONE BRIDGE

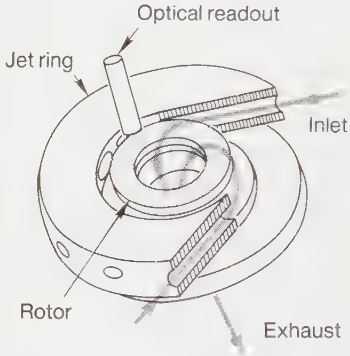


Differential pressure output signal is linear, proportional to mass flow rate, and independent of viscosity and density.

Constant-volume pump produces recirculating flow.

Impeller meters, such as axial turbine meters, are well known and widely used for medium and high flow rate measurement, but seldom operate well below 0.25 gpm. For low flows, several turbine meter manufacturers make tangential impulse versions, which measure liquid flow rates down to 0.001 gpm and gases to 0.001 acfm. Rangeability is usually 10:1. For accurate measurement, bearing friction must be minimized. Magnetic pickups, which are common on axial turbine meters, produce excessive drag and are seldom used on ultralow flow meters. Viscous drag is also a problem, and the meters are generally limited to low-viscosity fluids such as water, aqueous solutions, and thin fuels.

BEARINGLESS



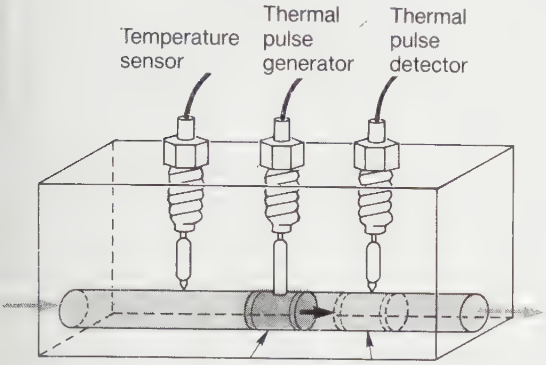
Jet action gives frictionless rotor movement at a rate proportional to flow.

An interesting variation on the impeller principle is the bearingless flow meter. In this design, fluid flows forward through tangential jets and around a washer-like rotor into a central cavity. The rotor has no vanes or bearings to support it. Jet action spins fluid within the cavity, carrying the rotor at a speed proportional to the volumetric flow rate. Light-reflective markings on the rotor are sensed by an optical pickup. The smallest bearingless flow meters read linearly down to 0.02 gpm, and nonlinearly down to 0.003 gpm. Applications are primarily for water and aqueous solutions.

Thermal flow meters, aside from rotameters, are the most widely used low-flow devices for measuring air and gas. These operate on the principle that a heated body in a flow stream is cooled at a rate determined by the velocity and density of fluid flowing past it. Thermal mass flow meters for low flow usually consist of a small-diameter, electrically heated tube, and a pair of thermocouples or resistance temperature devices (RTDs) near each end of the heated section. The difference between upstream and downstream temperature is a measure of flow rate. Temperature differential can also be held constant by varying heater current, which is used to indicate flow rate.

A thermal meter for liquids, which works on an entirely different principle, is the thermapulse flow meter. The meter measures the time required for a heated segment of liquid to travel down a small-diameter passage. This "time of flight" meter measures flow as low as 0.00033 gpm and is not affected by temperature, specific heat, or chemical composition.

THERMALPULSE

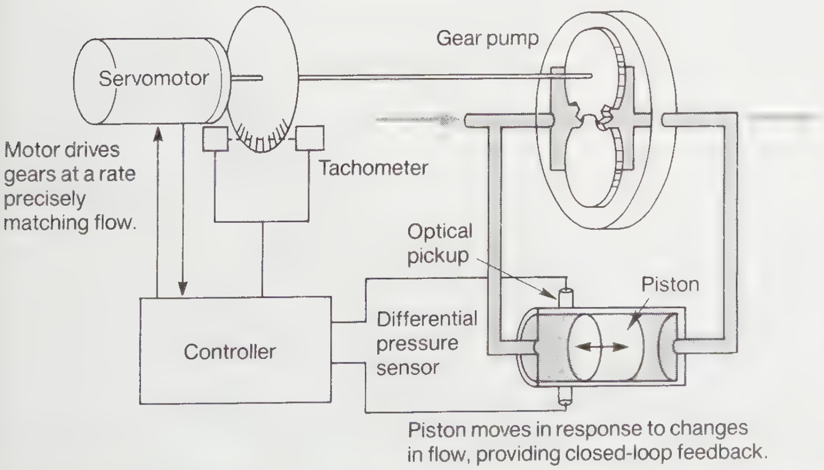


Positive-displacement devices have problems in measuring low and very low flow rates. One is that internal pressure drop necessary to move gears or vanes also produces internal leakage. At low flow rates, this introduces significant error. Also, flow-meter output is incremental. That is, a certain volume of fluid is needed to produce an output pulse. Displacement between pulses may not proceed smoothly or may be slightly different from one increment to another, and interpolation between pulses may produce errors.

One positive-displacement meter eliminates internal leakage by driving metering gears with a small, servo-controlled motor. A small piston in parallel with the gears is displaced downstream or upstream, depending on whether demand is greater or less than flow rate through the gears. An optical system senses piston position, providing closed-loop feedback to increase or decrease motor speed. The flow meters are precise, have good rangeability and respond quickly. They measure down to 0.00066 gpm with a 0.25% of reading accuracy.

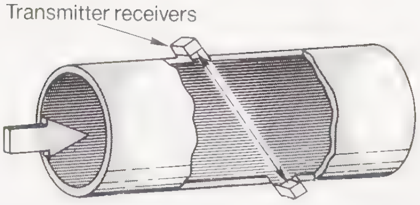
Several companies make piston flow meters that consist of four pistons in a single plane which are crank connected to a central shaft. They rely on small displacement and close clearances to provide reasonable pulse rates at very low flow, along with low internal leakage. Meters of this type claim ±0.5% accuracy of reading, turndown ratios as high as 100:1, and flow rates as low as 0.00027 gpm.

SERVODRIVE



Motor drives gears at a rate precisely matching flow.

Piston moves in response to changes in flow, providing closed-loop feedback.



ULTRASONIC

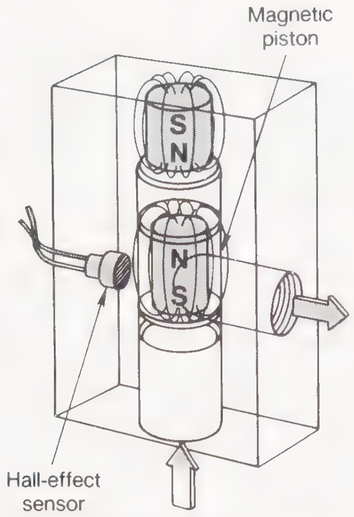
Ultrasonic meters use one of two methods, time-in-flight or Doppler. In the time-in-flight method, used with clean liquids, a high-frequency pressure wave is transmitted across the pipe at an acute angle. The time required for the beam to cross the pipe relates to flow rate. In the Doppler method, used with dirty liquids, the pressure wave is refracted back to a detector by particulates in the fluid. The difference between reflected frequency and transmitted frequency relates to flow rate. The meters are expensive, and accuracy ranges from ±1 to 4%, depending on particulate concentration.

Magnetic flow sensors operate on the principle that the movement of a conductor through a magnetic field induces a voltage. They consist of a flow tube which generates the magnetic field in the pipeline, and an electronic converter that measures induced voltage. The prime limitation of magmeters is that they require a conductive fluid. (Most fluids are, with the notable exception of petroleum-based fluids.) Because there is no obstruction in the pipeline, magmeters have no pressure drop and no parts that will wear out. Solids and contaminants are not a problem, nor is viscosity. These meters are highly accurate, typically 0.5% of flow rate over a dynamic range up to 300:1. But to maintain their accuracy, they must have a flow rate above 1.5 fps.

Magnetic piston flowmeters feature only one moving part, and accurately measure flow from 10 cc/min to 3.5 gpm, at pressures to 3,000 psi. Located in the flow path is a piston-shaped

Typical electrical conductivities

Liquid (18 to 25° C)	Conductivity (μmhos/cm)
Ethyl alcohol	0.001
Kerosene	0.016
Water (distilled)	0.04
Methyl alcohol	0.44
Nitromethane	0.6
Isopropyl alcohol	3.5
Formic acid	64.0
Water (NYC tap)	72.0
Latex	5,000
Calcium chloride (5% aqueous solution)	64,300



MAGNETIC PISTON

magnet, generally encapsulated in Teflon, that is free to travel in the flowpath bore. A second magnet of opposite polarity is located external to the flow stream, in line with the piston. The resulting magnetic repulsion opposes piston movement and provides resistance to flow.

In operation, flow lifts the piston off its seat, and the piston rises or falls as flow increases or decreases. Adjacent to the flow path, a Hall-effect transducer senses the resulting magnetic field and converts it to a millivolt signal. Because the magnetic field changes with piston position, the voltage produced by the transducer can be directly related to flow.

Laser-Doppler flow sensors differ from other types in that they measure flow at a point, not over an entire area. They are typically used to scan a flow field to gain specific details. The principle of operation involves crossing two laser beams in the flow path, creating interference fringe patterns with alternating light and dark areas. When flow passes through this pattern, light reflected by particles in the fluid correspondingly follows the light density variations, cyclically brighter and darker. The frequency of this cyclic variation is directly related to flow velocity. Dynamic range is about 100,000:1. Typically, these devices can measure velocities in the mm/s range at the low end, and a few thousand m/s at the high end. Accuracy in the range of a fraction of 1% is typical, and they are very good at following high-speed transients.

Gages and meters

Any fluid system may need to measure pressure, flow, or fluid level. Typically, measurements can be made with dozens of different types of gages connected directly to the system; alternatively, special sensors on the equipment can generate air or electrical signals that are displayed remotely on electrical meters or gages. If switches are necessary to initiate system action, they can be readily obtained; pressure and temperature switches are typically gaging elements with a snap-action or solid-state switch included.

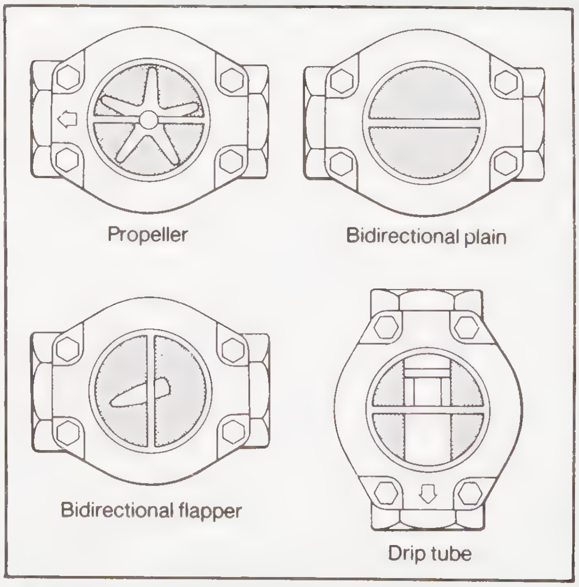
Fluid level in the reservoir can be monitored inexpensively. The simplest level-monitoring devices are dipsticks and sight gages. Dipsticks are most common on mobile systems; sight gages, on industrial systems. Together, these two devices take care of level-monitoring needs of most fluid-power systems. Where fluid level is critical, or where the level is unlikely to be observed periodically by the operator, low-level alarms actuated by float switches should be used, sometimes in conjunction with remote-reading gages. If potential damage from loss of fluid could be costly, the alarm circuit can be wired to shut down the system.

An alternative to the analog electromechanical system consists of a microprocessor (MPU), an analog-to-digital converter, a piezoresistive pressure sensor, and an operational amplifier. In this system, the pressure sensor generates a voltage in response to the pressure applied to it by the liquid in the tank. The pressure is a function of the liquid level in the tank. The sensor signal is converted from analog form into a digital signal by the analog-to-digital (a/d) converter. Most a/d converters require the millivolt sensor output to

SIGHT INDICATORS ALLOW FLOW CHECK

In-line sight flow indicators offer a simple, inexpensive means to qualitatively gage flow rate, direction, color, and clarity. Not only is this a reliable reading method, but it also allows personal interpretation by the viewer, who actually sees the product.

Typical applications are on filter, lubrication, and cooling lines, to positively verify fluid flow. Sight flow indicators are also used for troubleshooting, or as backups for meters, switches, process indicators, and other control devices.


Propeller
Bidirectional plain
Bidirectional flapper
Drip tube

A propeller indicator is the best way to show opaque liquids because of its high visibility. The propeller is also ideal for observation at a distance. But if flow rate is too low, the propeller will not turn. Another possible drawback to propeller indicators, depending on flow, is the restriction they add to the line. For example, a 2-in. diameter indicator with 100-gpm flow will produce a 10-psi pressure drop.

A bidirectional flapper not only indicates flow, but points in the flow direction. Also, flow restriction is low. For the same 2-in. diameter, 100-gpm flow, a flapper indicator causes only a 0.7-psi drop.

A plain bidirectional sight flow indicator without a flapper is used where observing color and clarity are more important than verifying flow. Advantage here is inherent simplicity.

A drip tube is used in vertical lines. It is ideal for gravity flow and for extremely low or intermittent flow. The drip tube ensures constant visibility by keeping the fluid from dripping onto the glass.

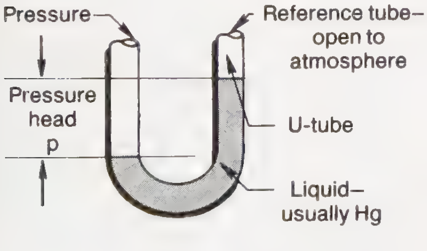
be amplified. For this reason, an operational amplifier (op amp) is included in the system.

The digital signal that the MPU receives from the a/d converter is manipulated so that it can be compared with data in lookup tables, which are stored in ROM. This comparison is used to determine the volume of liquid in the tank. Measurement accuracy depends largely on the number of levels chosen to define the tank and system calibration. The MPU then drives a display, either digital or analog, to show the level of liquid in the tank.

Temperature monitoring is often omitted from mobile systems, although some systems have remote-reading thermometers with a readout on the operator's control panel. Industrial systems typically have a thermometer installed as part of the sight-level gage or as a probe in the suction or return line. High and low-temperature alarms operated by thermostats are often used and may automatically shut down the system.

A word of warning: A thermometer installed in a sight-level gage does not indicate maximum system temperature. It indicates only the temperature of the fluid adjacent to that wall of the reservoir. Maximum system temperature can easily be as much as 130°F higher than that measured in the reservoir. The advantage of measuring reservoir temperature is that it indicates whether or not the system is operating normally — a substantial benefit considering that the thermometer typically costs less than a dollar.

Manometers are the simplest of all pressure gages. They permit readings of both absolute and differential pressure, with excellent accuracy. Dynamic response is poor, but static response is excellent. In basic form, manometers consist of a U-shaped tube about half-full of liquid. Pressure to be measured is fed into one tube, while the other (the reference tube) is either left open to the atmosphere or connected to a differential source. The height difference between the fluid legs is proportional to the applied pressure.



MANOMETER

Bourdon-tube gages are the most commonly used of all pressure gages. They are used almost exclusively for measurements in industrial hydraulic, and pneumatic systems, where pressures above 15 psi are expected. Accuracy of Bourdon gages is good to excellent, dynamic response is fair, and static response is excellent. The main working element in the gage is a tube (a Bourdon tube) shaped like a letter "C." As the pressurized fluid enters this tube, it tends to straighten it, moving the tube tip. The movement displaces a connecting linkage that actuates a pointer on the gage face.

Differential-pressure gages are available in Bourdon-tube mechanisms. Typically, they have two independent measuring chambers, each connected to a different pressure source. However, they have only one pointer, which shows the pressure difference between the two gages.

Diaphragm gages are based on a flexible diaphragm that is distended by pressurized fluid. As the diaphragm moves, it actuates a direct mechanical linkage attached to an indicator. Because of the way the diaphragm expands, these gages have a linear pressure-displacement relationship only over a comparatively narrow pressure range. They are normally used to measure pressures less than 15 psi.

Diaphragm gages can read both absolute and differential pressures with fair accuracy, fair dynamic response, and excellent static response.

Diaphragm gages should not be confused with diaphragm-protected gages. In these gages, the diaphragm does not actuate the pointer, but merely isolates the gage from the fluid being measured. Diaphragm-protected gages are usually filled with a temperature-stable fluid.

Bellows gages work like diaphragms, but have much greater extension to cope with wider pressure ranges. They are most useful over maximum pressure ranges from 0.5 to 150 psi. In this range, they can be used to measure both absolute and differential pressures with fair to good accuracy. Dynamic response is only fair, but static response is excellent. Bellows gages are troubled somewhat more by hysteresis and zero shift than other gages. ■

We handle uncommon requests. Fast.

So imagine how quickly you'll get this.

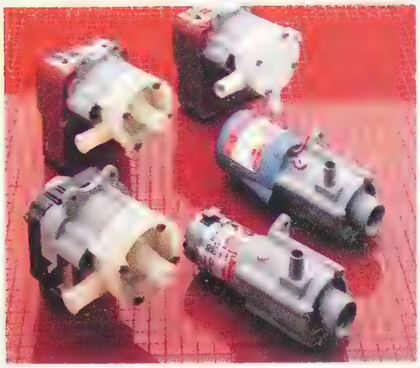
AMERICAN CENTRIFUGAL delivers a stepless range of tube sizes:
- Wall thicknesses – 0.5" to 6.75"
- Outer diameters – 4" to 55"
- Length – 4' to 20' or longer using proven splice welding
- Tensile properties and impact strength to specification

AMERICAN CENTRIFUGAL
FACILITIES • SERVICES • MATERIALS

And because our tubes are CERAM-SPUN®, your special order is no problem. So, don't wait. For your free brochure, call (205) 325-7705 or fax (205) 325-8193.

AMERICAN CENTRIFUGAL

Circle 476



SMALL COMPACT PUMPS—The March Series 1 offers small compact pumps with seal-less, leak proof construction, and very quiet operation. In one application these pumps are used to recirculate water in hospital thermal blankets. Water is heated or cooled as required to control the patient's body temperature. Pump can run practically dry or completely dry for long periods without damage to the pump or motor. This series includes submersible models as well as models that can be used submerged or in open air. **March Manufacturing Company.**

Circle 477

MARCH

ORIGINATORS OF THE
SEAL-LESS MAGNETIC DRIVE PUM

offers the ultimate in reliable, trouble-free performanc
no shaft seal to wear, leak, replace, or reduce power.

March not only offers the broadest selection of precision centrifugal pumps for a wide range of O.E.M. and chemical applications, but even more important, March delivers the ultimate in reliable trouble-free performance.

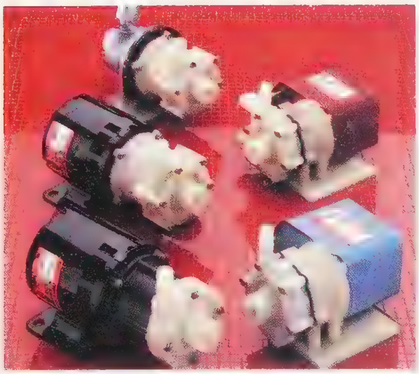
March seal-less magnetic drive pumps eliminate costly and sometimes dangerous leakage and power draining friction. And under adverse conditions, the magnetic drive acts as a clutch to eliminate overloading and motor burnouts. When you need to replace a motor, it can be done in minutes without draining the system.

March's broad line of pumps for corrosive applications includes specially designed pumps for high acid concentrations, alkalis, solvents, and highly corrosive applications.

And March, originators of the magnetic drive pump, has the experience know-how, and flexibility to design and manufacture production run pumps to meet your special requirements.
Send for catalog.

MARCH
MANUFACTURING INC.
1819 Pickwick Avenue
Glenview, Illinois 6002
1 708 729-5300
FAX: 1 708 729-7062

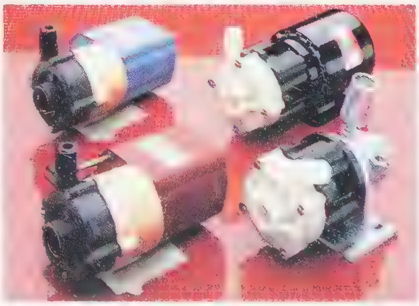
Circle 479



MARCH SEAL-LESS PUMPS ELIMINATE LEAKAGE—Series 2 and Series MDX seal-less pumps are used for recirculation of various liquids in film and x-ray processors in silver recovery systems, in photo chemical mixing systems, and graphic arts equipment. These seal-less magnetic coupled pumps eliminate sucking air into the solution, and prevent any liquid from leaking out of the pump. **March Manufacturing Company.**

Circle 478

MARCH PUMPS USED IN WIDE RANGE OF APPLICATIONS—



March seal-less magnetic coupled pumps are used for movement of liquids in ice making machines, coffee dispensers, aquarium systems, film processors, solvent cleaning systems, EDM machines, plating filter systems, etching equipment, marine air conditioning systems, water purification systems, cooling systems for computer equipment and CAT scan machines. as well as dialysis systems, and waste treatment. Particularly suited for applications where rotating shaft seal failures create a problem. **March Manufacturing Co.**

Circle 480

Power input and storage

Converting mechanical energy to fluid form provides the "muscle" in a fluid-power system.

The power source is the key element in a fluid-power system. In a pneumatic system the power source is an air compressor, while in fluid-power systems it is a pump. These normally are driven by an electric motor or internal combustion engine. Various concepts are applied to convert the mechanical energy from a motor or engine to fluid energy in the system.

Most systems can be made to work more efficiently when something is installed in the system to allow storage of temporarily unneeded fluid delivered from the pump or compressor. In hydraulic systems, the storage device, of course, is an accumulator; in pneumatic systems, it is a tank or receiver. However, most pneumatic systems are used with a receiver. The decision to use an accumulator in a hydraulic system is less clear-cut, but that decision can affect the choice and application of a hydraulic pump.

In some hydraulic systems, intensifiers or "boosters" replace pumps or compressors. They are most often used when one form of fluid energy is available, but a specific system must use another form. Most commonly, such need exists in a plant in which compressed air is readily available, and a hydraulic system is required for a specific small job. In that kind of task, an air-powered intensifier lets the pneumatic system power the hydraulic circuit, without requiring a new prime mover. Because these devices are directly competitive with pumps on some jobs, and complementary on others, they are included in this section.

Compressors

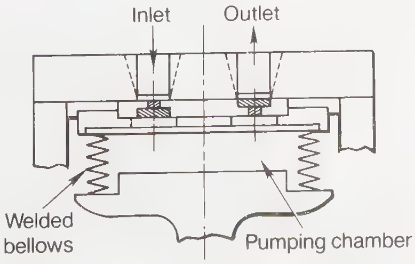
The main difference between pumps and compressors is that the fluid delivered by compressors — air — is compressed and under pressure at the time it is delivered, even if there is no load on the system. Most devices used to compress air are very similar in concept and — perhaps even in hardware — to hydraulic pumps, and selection considerations are similar.

The only other substantive difference is that most hydraulic systems are powered by a single pump that is actually a part of the system, whereas a host of pneumatic systems are often powered by a single compressor, which is almost a "utility" in the plant like water or electric service. Nevertheless, many small compressors are available for specific, discrete jobs; typically they are positive-displacement compressors. Dynamic, or nonpositive-displacement compressors are typically larger, facility-type units.

Compressors are fairly simple devices, capable of long periods of maintenance-free operation if properly integrated into pneumatic systems. Yet time and again they suffer from early failures because obvious precautions were ignored during system design. Four basic rules can provide substantial improvement in compressor life with only moderate design effort:

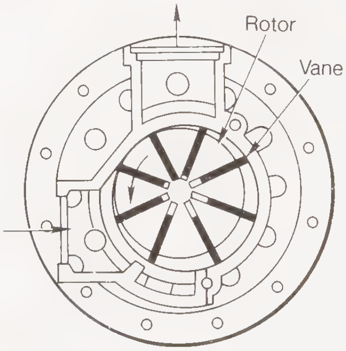
- Pumps and compressors should be sized to provide at least the required pressure and flow, and preferably 10 to 25% more.
- Filters should be selected to protect the pumping unit, and sometimes to protect downstream components or products as well.
- Relief valves should be selected to keep pressure or vacuum at appropriate levels.
- Pumping units should be placed in a clean, cool, dry environment.

Bellows compressors consist of a welded metal bellows connected to inlet and outlet ports with check valves. These compressors typically cover the pressure range up to 10 psig, and are used in pollution detecting and measuring devices, gas-sampling instruments, and medical applications. Lubrication is not needed, allowing high purities to be maintained.



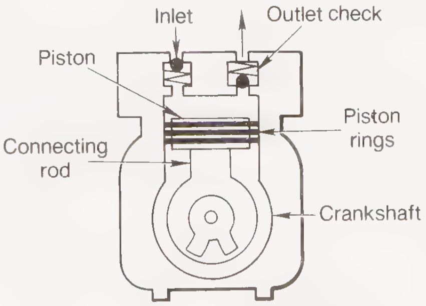
BELLOWS COMPRESSOR

Vane compressors are simple machines with few moving parts. Like their hydraulic counterparts, vane pumps, the compressors are inexpensive, with low operating cost, and low starting-torque requirement. They are compact and relatively vibration free, with little pulsation in the compressor output. The sliding vanes are closely fitted in the rotor slots and wear very little during operation. These compressors are available in power ranges from 10 to 500 hp, at pressures to 150 psi.



VANE COMPRESSOR

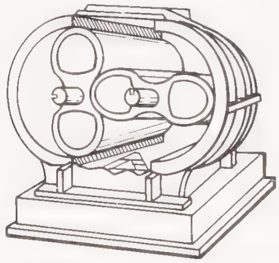
Reciprocating compressors consist of a piston moving within the cylinder to trap and compress the gas. In principle, such a unit is like an automobile engine, with the pistons compressing the gas and valves controlling its inlet and outflows. Sizes range from less than 1 to over 5,000 hp. Reciprocating compressors have good part load efficiencies and are useful for wide variations in operating conditions.



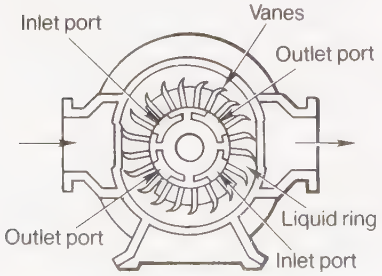
RECIPROCATING COMPRESSOR

Diaphragm compressors are a modification of the reciprocating compressor. Compression is performed by the flexing of a metal or fabricated diaphragm which is caused by the motion of a reciprocating piston in a cylinder under the diaphragm. The space between the diaphragm and the piston is usually filled with liquid.

Lobed-rotor compressors have two rotating elements that revolve in opposite directions in a chamber. In most compressors, the rotors do not actually touch and do not drive each other, being driven instead by timing gears. Because the rotors do not actually touch, air leaks between them at a small but constant rate. This leakage, called "slip," is constant for a given compressor at a given pressure. For highest efficiency, these compressors should be operated at maximum speed. They are available in power ranges from 7 to 3,000 hp, delivering pressures to 250 psi. Because the internal lobes do not contact, they need no lubrication.


LOBED-ROTOR COMPRESSOR

Liquid piston compressors have no moving parts in wearing contact. A rotor with multiple forward-curved blades rotates in an elliptical casing. Fluid, trapped within the casing, is carried around the inner periphery by the blades. Space between the blades changes volume due to the elliptical fluid path, and the inner surface of the liquid ring trapped between the blades serves as the face of a liquid piston. These compressors accept liquid slugs and fine particles without serious damage. Lubrication is required only in bearings located outside the pump housing. These compressors deliver up to 150 psi throughout the range of 10 to 500 hp.

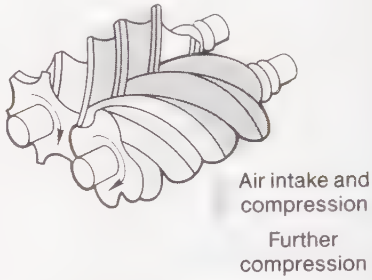


LIQUID-PISTON COMPRESSOR

Centrifugal compressors are best suited to moving large volumes of air at relatively low pressures. Basically, they consist of a high-speed rotating impeller, a diffuser section where velocity is reduced and pressure increased, and a collector section that further reduces velocity and increases pressure. Centrifugal compressors can handle high flow demands well, but when demand decreases much below rated flow and output pressure rises, the compressors can surge. In surge, the pressure field at the compressor outlet varies randomly. If allowed to continue, this condition can damage bearings, blades, and even the housing itself. Centrifugal compressors typically use from two to six stages, supplying from 400 to 3,000 cfm at speeds to 20,000 rpm.

Regenerative blowers (also known as peripheral blowers) use a disclike impeller with blades mounted around its outside edge. As the impeller revolves, air is drawn into the space between the blades. Centrifugal force moves the air in a spiral path outward to the housing, where it slips by the initial blade and returns to the base of the succeeding blade, where the process is repeated. In some models, a flow splitter creates two flow paths, so that the air must make two circuits around the impeller. In other models, the splitter is omitted, and the air makes only one circuit before exiting. Regenerative blowers provide air flows up to 1,000 cfm and pressures to 8 psi.

Helical compressors look like two giant screws meshing together; they work much like hydraulic screw pumps. Maximum pressure from these machines is approximately 125 psi in single-stage configurations. Helical compressors may be either oil flooded or dry.



HELICAL COMPRESSOR

Dry helical compressors, like lobed units, require timing gears to maintain proper clearance between the rotating elements. These units are most efficiently operated at high continuous speeds.

Flooded compressors do not require any timing gears, because the oil-laden screw surfaces can drive each other. However, oil separators are needed to remove the oil from the air as it leaves the compressor. They are

SMALL COMPRESSORS AND VACUUM PUMPS

Air is generally delivered to plants by a central compressor, which also powers pneumatic systems. In such installations, the initial cost of pneumatic controls is as low as that for electrical controls. But the use of a central compressor can cause problems that increase the operating cost, especially on complex machinery.

Problems arise because plant air systems are often dirty, and dirty oil/water mixtures eventually contaminate the compressed-air system. Line filters are available to remove dirt, oil, and water from plant air, but the filters must be maintained, adding to the cost. Moreover, when air is compressed, moisture condenses. So dryers must be installed and maintained, further increasing operating costs.

Oil carryover also is a problem when large lubricated compressors supply the plant air. Oil and water combine to form gum that can clog an air-logic control system. Filters are available to offer protection from oil carryover, but a filter need go unchanged only once, and the entire air-logic circuit will need cleaning. Such costs for cleaning and equipment downtime significantly increase operating expenses of pneumatic systems powered by a central compressor.

Cost penalties can be avoided by using a small oilless air compressor or vacuum pump, dedicated to the machine in question, rather than a plant-wide system. Such installations reduce maintenance costs because these compressors produce cleaner, drier air, eliminating the need for conditioning equipment.

A LONG LINE OF LOW COST PROVEN PERFORMERS

Tuthill's L and C Series Pumps

lubricating ▪ transfer ▪ hydraulic ▪ circulating

- Lower cost, longer lasting.
- Internal gear pumping design—only two moving parts.
- Reduce downtime and maintenance costs.

Tuthill's internal gear rotary pumps have earned acceptance as the industry standard for lubricating, low pressure hydraulic, transfer, circulating, burner oil and many other industrial pump applications.

Precisely machined and assembled with only two moving parts, they achieve and retain their reliability over a wider range of viscosities than alternative pump designs. And they're substantially quieter than spur gear, vane, and other pump styles.

Rotors are precision milled and ground from bar stock—and in larger models bushing support is provided for the rotor shaft for longer lasting reliability. Equipped with a mechanical seal, lip seal, or packing—available in a number of different materials, these pumps can meet almost any temperature or fluid compatibility requirement.

Available in a wide range of configurations with capacities from .5 to 84 GPM. Tuthill application engineers will work with you in adapting the internal gear design for the greatest possible advantage in your application.

Send for catalog or phone for information

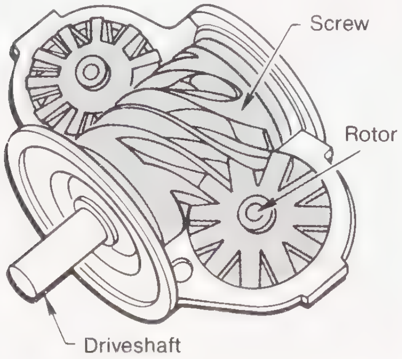
TUTHILL CORPORATION | **Tuthill Pump Division**

12500 South Pulaski Road
Chicago, Illinois USA 60658 Tel 708 389-2500
Fax 708 388-0869 Telex 3781847 or 6974251

Circle 481

available over a power range of about 7 to 300 hp.

Single-screw compressors are based on the same principle as helical compressors. As the central screw rotates, air trapped between the screw teeth is compressed against the star-shaped rotors. These compressors tend to have low vibration and noise levels, and low discharge pressures. Lubrication is required.



SINGLE-SCREW COMPRESSOR

Vacuum pumps

In principle, industrial vacuum pumps are merely compressors run with the inlet attached to the vacuum system and the outlet open to exhaust. In smaller sizes, compressors and vacuum pumps are often identical machines. However, in the large sizes that might power a plant-wide vacuum system, the machines differ in minor ways that are intended to enhance efficiency for one application or the other. Manufacturers strongly advise that the same machine not be used for both vacuum and compression at the same time. The heavy loads will damage it.

Three criteria control pump selection: degree of vacuum produced, rate of air removal, and power requirement. However, applications such as filtration may subject the unit to the ingestion of foreign material.

The first pump performance criterion is the vacuum it produces. Manufacturers provide a maximum vacuum rating expressed as absolute pressure in mm Hg, or vacuum in in. Hg. Larger units are usually rated only for continuous duty, but smaller units may have a higher vacuum rating for intermittent duty. In smaller units, temperature-rise considerations limit the vacuum that can be produced.

Continuous and intermittent vacuum ratings are determined for standard atmospheric pressure: 29.92-in. Hg. Lower ambient pressures reduce the vacuum that can be produced. The

SELECTING SUCTION CUPS

Suction cups are widely used in pick-and-place applications because vacuum is clean and efficient. A common concern in these uses is sizing a cup to provide sufficient lifting force. However, while this force — determined by the degree of vacuum and cup area — is important, other factors, particularly the material and type of cup, can be more critical to optimum and efficient operation.

When designing a vacuum system with suction cups, first determine the working environment and select the material. Most applications can be handled by a standard material like chloroprene. If temperature extremes are involved, silicone is recommended. If the cup will contact food, FDA-approved silicone is the choice. And if oils or lubricants are present, Terban is recommended. Many manufacturers also produce cups from nonstandard material to meet special needs.

Next, consider the product to be moved, and analyze shape, weight, and available surface area. For example, in lifting a curved surface, a flat cup has limited capability. Some manufacturers offer a free trial use of their products, or are willing to examine a product and recommend a particular cup to meet the need. The most common types of cups are:

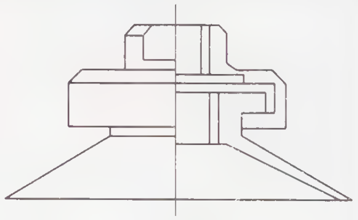
Universal: Considered standard, light-duty cups, universal cups can handle slight surface curvature, but they mainly are for flat, even surfaces. Typical cup diameters range from ½ to 2 in.; thus, they are usually used for small, lightweight items such as electronic components.

Bellows: These cups are widely used because they compensate for many unforeseen or incalculable variances, such as surface waviness or bending under load. In the packaging industry, for example, opening a box will cause the surface to bend, and a bellows can compensate for the bending. These are "safe" cups because they are more forgiving and accommodate many design mistakes or undetectable flaws.

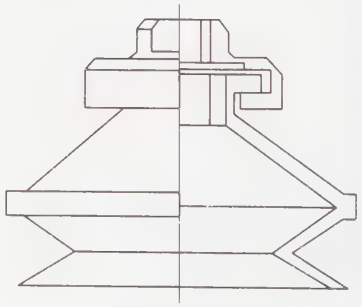
Multiple bellows: These cups offer the same benefits as bellows. In addition, longer cup movements compensate for any variation in product height, which is especially important if a robotic arm or cylinder has a limited amount of travel. While flat cups handle only uniform-size materials, larger multiple-bellows cups have about 1⅓ in. of play.

In certain instances, creating a vacuum will cause bellows cups to retract and pull up. In such cases, the devices can be used as actuators. With small, lightweight products, this can eliminate a cylinder typically necessary for vertical motion.

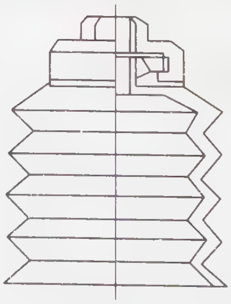
Because multiple bellows offer more height compensation, they are sometimes used to reach over the top of a product, such as a tapered bottle or an egg, and grip on the sides. Cups are thin and flexible, and are widely used in the food industry to pick up a variety of materials.



UNIVERSAL



BELLOWS



MULTIPLE BELLOWS

Deep cups: These are specialty cups for irregular shapes, such as lifting angle iron, because they lift across corners and edges. Deep cups are often used to pick up tubing or pipe because they conform to curved surfaces. The cups are intended for special applications and are not widely used because a bellows can often do the same job. However, deep cups offer more support than a similar size bellows cup.

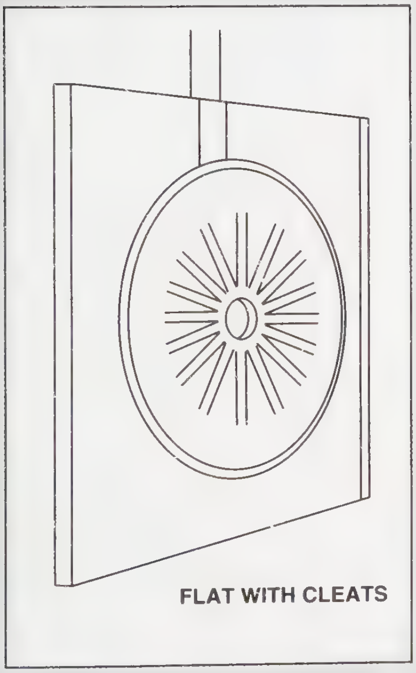
Flat with cleats: These widely used cups have much the same design as universal cups, except that they have radial cleats extending from the cup center. These interior ribs extend to within about ¾ in. of the outer edge to help maintain vacuum over the entire cup surface. This is important when pulling high vacuums, because an unsupported cup can collapse, lose vacuum, and drop the product. When lifting very-thin plastic or foil sheets, the ribs prevent material from being drawn into the cup.

Valve cups: These standard cups contain a spring-loaded check valve that allows vacuum to flow through the suction cup on contact with a surface. The valve seals off the vacuum when not in use. Valve cups are typically used when picking up a variety of products that differ in shape, or where the number of items to be moved varies. For example, when picking up boxes, where the number of boxes changes with each cycle, the cups not being used do not leak. With conventional cups, absence of a product beneath one cup can create enough leakage that the other cups cannot provide sufficient lift. Also, if product size changes, there is no need to change the setup. However, valve cups require flat surfaces to activate the valves.

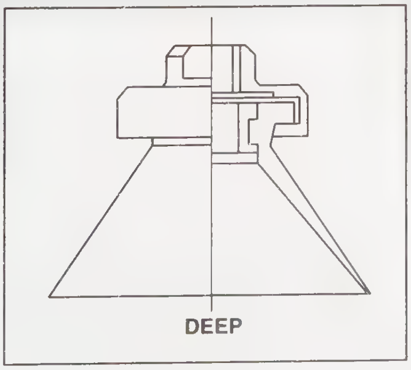
Another benefit is that vacuum is stored right at the cup. When activated, only the air in the cup must be evacuated. The result is extremely fast-acting cups. Also, vacuum acting on the valve creates a natural pulling force; thus, only a few grams of additional force are needed to activate the valve.

Custom: Many times, special designs must be created, such as an oval cup or a special size of a standard design. This is dictated by the weight and available surface area of the object to be moved. In some cases, accessories such as ball joints or level compensators allows certain cups to work more efficiently on a given surface. The devices might allow a flat cup to provide the same benefits of a bellows cup in compensating for a variation in height or positioning of the product to be lifted.

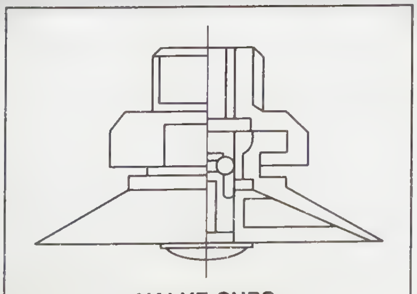
Often, one or more standard round cups do not provide sufficient lifting capacity, or would require a larger vacuum pump. In such cases, a special cup may be more economical or the only practical approach. Here, it is more important to pick the cup first, not the pump. Often, designers make the mistake of oversizing the pump to compensate for an inadequate cup when a special will do the job with a smaller pump. The larger the surface area, the lower level of vacuum and the less energy that is required.



FLAT WITH CLEATS



DEEP



VALVE CUPS

rating is determined from:

$$v_a = \frac{v_o P_a}{29.92}$$

where v_a = adjusted vacuum rating, in. Hg; v_o = original vacuum rating at standard conditions, in. Hg; and P_a = anticipated atmospheric pressure at the application site, in. Hg.

Rate of air removal is the second criterion. Vacuum pumps are flow rated according to the volume of air exhausted with no pressure differential across the pump. Manufacturers provide curves showing free air delivery at rated speed for vacuum levels ranging from 0-in. Hg (so-called "open capacity") to maximum vacuum rating. Some manufacturers also provide curves of capacity at different speeds for a given vacuum.

The last pump criterion is power requirement. Compared with air compressors, vacuum pumps require relatively little power. At low flows, vacuum (or pressure differential) is high; at high flows, vacuum is low. Therefore, power, which is proportional to flow and pressure differential, is generally low.

Power output of the pump can be found from pressure-flow curves provided by manufacturers. Input power and speed requirements are also shown in the data. Overall pump efficiency (including both volumetric and mechanical efficiency) can be evaluated by combining this data. This is done by dividing the free-air capacity of the pump at the required vacuum level by drive power required at that condition. The result is proportional to the product of gage vacuum and air-flow rate and is representative of efficiency.

All three performance criteria — vacuum, flow and power — can be affected by pump temperature. At higher vacuum levels, little air flows through the pump, so little heat is transferred to the air. Much of the heat generated by friction must be dissipated by the pump. This heat gradually raises pump temperature and can drastically reduce service life. Temperature excursions are especially important to intermittent-duty pump, which can overheat if on time greatly exceeds off time.

Vacuum pumps are classified as either positive or nonpositive displacement. A positive-displacement pump creates vacuum by isolating and compressing a distinct, constant volume of air. The compressed air is vented out one port, and a vacuum is created at the other port where the air is drawn in. This generates relatively high vacuum, but little flow.

A nonpositive-displacement pump, on the other hand, uses rotating impeller blades to accelerate air and create a vacuum at the inlet port. While nonpositive-displacement pumps cannot produce high levels of vacuum, they provide high flow rates.

Principal types of positive-displacement vacuum pumps include piston, diaphragm, rocking-piston, rotary-vane, lobed-rotor, rotary-screw, and liquid-ring designs.

Reciprocating-piston pumps generate relatively high vacuums — from 27 to more than 29 in. Hg — under a variety of operating conditions. Typical pumps of this type have one or more pistons linked to a rotating crankshaft. The alternating piston action moves air past check valves in the cylinder head to create a vacuum at the inlet port. Lubricated piston pumps are quieter, produce less vibration, have a higher capacity, and feature a much longer life than oilless designs, but they are also heavier and more expensive.

Diaphragm pumps offer the advantage of the fluid chamber being totally sealed from the pumping mechanisms. An eccentric connecting rod mechanically flexes a diaphragm inside the closed chamber to create a vacuum. This results in somewhat lower vacuum compared to that produced by a reciprocating piston. However, the diaphragm's lower compression ratio — low flow, large diameter, and short stroke — makes for quiet, economical, and reliable operation. The design is available in both one and two-stage versions. Single-stage pumps provide vacuum up to 25.5 in. Hg, while two-stage units are rated to 29 in. Hg.

Rocking-piston pumps combine the compact size and quiet, oilless operation of the diaphragm pump with the high-vacuum capabilities of the reciprocating-piston pump. Here, a piston is rigidly mounted (no wrist pin) on top of the diaphragm unit's eccentric connecting rod. An elastomeric cup skirts the piston and functions both as a seal — equivalent to the rings on a piston compressor — and as a guide member for the rod. The cup expands as the piston travels upward, thus maintaining contact with the cylinder walls and compensating for the rocking motion. The absence of a wrist pin is the key to the pump's light weight and compact size.

Single-stage rocking-piston pumps produce vacuum to 27.5 in. Hg; two-stage designs can generate 29 in. Hg or more of vacuum. Rocking-piston pumps are also relatively quiet, operating at sound levels as low as 50 dBA. A drawback to rocking-piston pumps is that they cannot generate a lot of airflow. Even the largest twin-cylinder models have flow rates of less than 10 cfm.

Rotary-vane pumps use a series of sliding, flat vanes rotating in a cylindrical case to generate vacuum. As an eccentrically mounted rotor turns, the vanes slide in and out, trapping a quantity of air and moving it from the inlet side of the pump to the outlet.

Rotary-vane pumps usually have lower vacuum ratings than piston pumps, in the 20 to 28 in. Hg range. However, there are a few exceptions. Some two-stage, oil-lubricated designs have vacuum capabilities up to 29.5 in. Hg. Pumps with recirculating oil systems reach still higher vacuums, in the less than 1-torr range. The pumps offer a number of advantages, including high flow capacities, low starting and running torque requirements, vibration-free operation, and continuous airflow. No valves restrict flow or require maintenance in the rotary design. The compact units are also quiet, generating as little as 45 dBA or sound.

Depending on the application and vacuum level required, an economical alternative to using a high-vacuum pump is two standard, staged rotary-vane pumps. Or, a high-volume, low-duty pump rated for continuous duty of 20 in. Hg sometimes can be operated at restricted airflow or "blanked-off" conditions for short periods of time to provide higher vacuums. As with other types of pumps available in both lubricated and oilless configurations, lubricated rotary-vane pumps are capable of slightly higher vacuum compared to oilless designs.

Liquid-ring pumps feature a multiblade impeller, mounted eccentrically in a cylindrical case that is partly filled with water. As the impeller rotates, liquid is thrown outward by centrifugal force to form a liquid ring concentric with the periphery of the casing. Due to the eccentric position of the impeller, the air space in the impeller cell expands during the first 180° of rotation, creating a vacuum. During the next 180° of rotation, the air space is reduced, discharging compressed air and water. In addition to being the compression medium, the liquid ring absorbs the heat of compression as well as any powder or liquid slugs entrained in the air.

Rotary-screw and lobed-rotor vacuum pumps are two other types of positive displacement pumps. Neither lubricated design is as widely used as rotary-vane and piston pumps, especially in smaller sizes. Due to the size of the gears and rotors, both designs lend themselves to larger installations.

A rotary-screw pump's vacuum capabilities are similar to those of piston pumps, with the added advantage of being nearly pulse-free. Two meshing rotors with helical contours trap air as the screws turn in opposite directions. This action creates chambers of decreasing volume behind and increasing volume in front of the rotor chambers.

Lobed-rotor pumps bridge the gap between positive and nonpositive-displacement units. The pumps have a pair of mating lobed impellers that rotate in opposite directions, trapping air and withdrawing it from the system.

High-speed, multistaged centrifugal blowers and regenerative blowers are the major types of nonpositive-displacement pumps, generally operating at high speeds and attaining moderate vacuum levels.

Centrifugal blowers, for example, are an excellent choice where only intermittent use is required. To keep costs down, a short-life brush-type ac or dc motor powers these blowers, which are widely used in vacuum cleaners.

Regenerative blowers have many advantages because individual air molecules pass through many compression cycles with each revolution compared to the single compression per stage for multistaged centrifugal types. At first glance, regenerative blowers are similar to rotary-vane pumps, but have a special blade and housing configuration.

As the impeller rotates, centrifugal force moves the air molecules from the blade root to its tip. Leaving the blade tip, the air flows around the housing contour and back down to the root of a succeeding blade, where the flow pattern is repeated. This action provides a quasi-staging effect to increase pressure differential capability. The speed of the rotating impeller determines the degree of pressure change.

The end result is not a particularly high vacuum — approximately 100-in. H_2O in single-stage models. But flow capacity is very high, up to several hundred cfm. Multistage versions produce higher vacuum levels, but at lower flow rates.

Fluid-transfer pumps

Fluid-handling or transfer devices are not basically concerned with the modulation or transfer of power, but only with the movement of fluid. Two major types of fluid-transfer pumps are positive-displacement (either bulk-handling or metering pumps) and nonpositive-displacement (centrifugal).

Airtight Solutions For OEMs.

Give your products airtight quality and dependability with standard or custom-designed air compressors or vacuum pumps from Thomas Industries. As the world's most reliable, broadly accepted line of small OEM air motors, piston, diaphragm, and rotary vane air compressors and vacuum pumps, we provide the perfect answer to your application needs. Specify Thomas, Pneumotive, and ASF brands. Our superior air products from 1/32HP through 15HP promise lower maintenance, long life and top efficiency. For more information contact North American Compressor and Vacuum Pump Group, 1419 Illinois Ave., Sheboygan, WI 53082, 414-457-4891.

THOMAS
INDUSTRIES INC.

Air Compressors & Vacuum Pumps.

Circle 482

POWER AIR OEM AIR COMPRESSORS

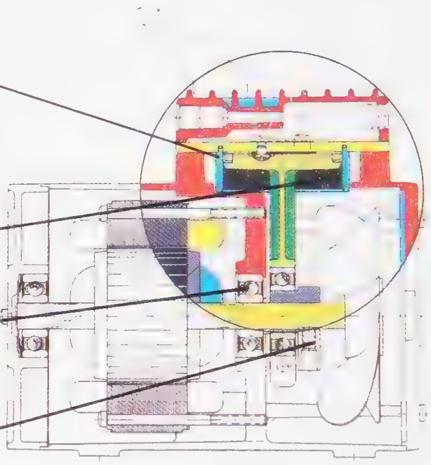
Standard stock or custom

As a company structured to serve the OEM, we know most OEM applications have precise requirements in terms of cost, space, noise level, heat, power, vibration, service life and more. And we offer a wide selection of standard air compressors and vacuum pumps that meet these requirements for most applications. If one of our standard units does not meet your exact requirements, we're able, through our unique design and engineering expertise, to modify a standard unit or even develop a completely new design. The result: a custom air compressor or vacuum pump that meets the exact OEM application requirements at the lowest possible cost.

Oil-less WOB-L® piston-type air compressors and vacuum pumps

Thomas revolutionized the efficiency of piston air compressors and vacuum pumps with the introduction of the unique oil-less WOB-L® piston. The reason is simple. Our design has fewer moving parts resulting in reduced noise and vibration, less friction and wear, and far less maintenance.

Available in a wide selection of configurations and sizes ranging from 1/12 HP to 1 HP.



Rugged, flexible cup of Teflon® compound expands with use to maintain an excellent seal, provide high efficiency and consistent performance.

Flow-through ventilation provides superior cooling and lower discharge air temperature.

Long-life Teflon® impregnated cylinder is hard-coated with aluminum alloy for greater durability.

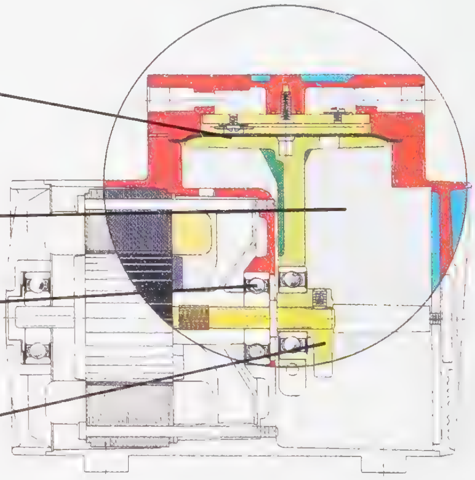
Permanently lubricated ball bearing construction offers a long service-free life in continuous duty applications.

Balanced eccentrics provide smooth, low-vibration operation.

Oil-less diaphragm-type air compressors and vacuum pumps

Drawing on more than 50 years of experience in the manufacture of high-performance, long-life diaphragm air compressors and vacuum pumps, Thomas today offers one of the finest lines of oil-less diaphragm-type units available to the OEM.

Available in a wide selection of configurations and sizes ranging from 1/32 HP to 1/2 HP.



Several long-life diaphragm options are available for specific applications.

Corrosion protection coatings available for most applications.

Closed crankcase available in standard models is designed for low noise operation.

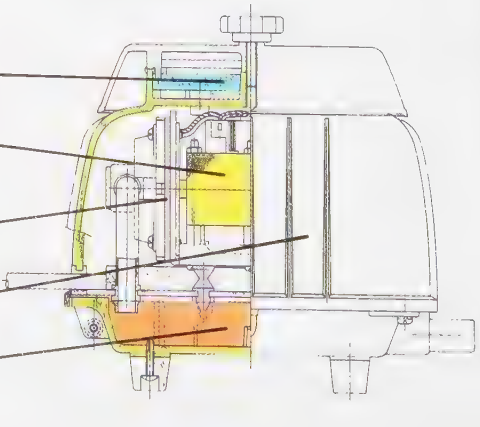
Permanently lubricated ball bearing construction offers a long service-free life in continuous duty applications.

Balanced eccentrics provide smooth, low vibration operation.

Oil-less linear-type air compressors

Thomas' new line of oil-less, high efficiency linear air compressors are designed to meet the demand of high flow—low pressure applications.

Available in several models ranging from 4.1 to 7.2 PSI maximum pressure.



Reusable air filter that can be removed, cleaned and replaced.

Energy source has low power consumption and low starting current amp draw.

Long-life diaphragm for dependable performance.

Cast aluminum housing for quiet operation.

Chamber designed for low pulsation.

ND VACUUM PUMPS

THOMAS
INDUSTRIES INC.

Oil-less WOB-L® Piston Air Compressors and Vacuum Pumps

MODEL NUMBER	NOMINAL HP	VOLTAGE/ HERTZ/ PHASE	COMPRESSOR PERFORMANCE PSI VS. CFM								MAX. PRESS. PSI		VACUUM PERFORMANCE IN. HG VS. CFM						MAX. VACUUM IN. HG
			0	5	10	20	40	60	80	100	CONT.	INT.	0	5	10	15	20	25	
010CA26	1/25	115/60/1	.37	.33	.29	20					10	30	37	27	18	.10	.02		22.3
004CA33	1/12	115/60/1	48	45	42	34	25				20	40	48	41	31	21	.11		27 2
004CDC33	1/20	12V DC	.51	48	43	36	19				20	50	51	40	29	18	.10		25 1
215ADC38	1/8	12V DC	97	92	87	76	61	46	.38	.30		120							
315CDC50	1/5	12V DC	1 18	1 12	1 09	1 03	89	76	66	56		210	1 18	86	58	.29			21 0
405ADC38*	1/10	12V DC	92	81	71	61	53	.44	35	27	100	100							
405AE38	1/12	115/60/1	83	78	75	67	54	43	34	26	50	100							
415CDC30	1/10	12V DC	.92	.86	.81	.71	.55	.44	.34	.25	100	100	.92	.75	.54	.34			24.6
607CA22*	1/8	115/60/1	.84	.79	.74	.64	.46	.31	.20	.10	100	100	.84	.62	.46	.31	.15		25.9
607FA22	1/8	115/60/1	.84	.79	.74	.64	.46	.31	.20	.10	100	100	.84	.62	.46	.31	.15		25.9
607CA32*	1/7	115/60/1	1.22	1 16	1 10	97	74	56			50	60	1.22	87	65	45	23		26.8
607CE44*	1/3	115/60/1	1.60	1.54	1.48	1.37	1.21	1.05	.91	.76	100	100	1.60	1.15	.90	.62	.33	.11	27.6
619CE44*	1/5	115/60/1	2.00	1.85	1.80	1.60					35	35	2.00	1.20	.96	.64	.36		26.0
707CK50	1/4	115/60/1	2.70	2.57	2.45	2.24	1.95	1.62	1.38	1.11	100	100	2.70	1.99	1.54	1.12	.65	.20	27.7
807CK60	1/3	115/60/1	3.25	3.15	3.05	2.80	2.34	2.01	1.75	1.47	100	100	3.25	2.07	1.60	1.1	.6	.21	27.7
1007CK72	1/2	115/60/1	4.05	3.88	3.70	3.35	2.93	2.57	2.29	2.05	100	100	4.05	2.49	1.93	1.3	.8	.28	27.9
1107CK75	3/4	115/60/1	4.25	4.00	3 88	3.60	3.07	2 77	2 45	2 18	100	100	4 25	2.70	2.01	1.40	.86	.29	27.4
2607CE22	1/4	115/60/1	1.68	1.61	1 55	1 40	1 10	80	60	40	100	100	1 68	1.20	.93	.63	.33		26.2
2608TE22/18	1/3	115/60/1	71	.70	.69	67	64	62	59	55	160	160							
2608VE44	1/3	115/60/1											1 60	1 20	98	69	48	.16	29 0
2618CE44*	1/3	115/60/1	3.15	3.04	2.93	2.72					25	25	3.15	2.30	1.60	1.10	.6	.18	27.6
2619CE44*	1/3	115/60/1	3.75	3.65	3.50	3.20					40	40	3.75	2.75	2.15	1.49	.86		27.3
2621CE564	1/3	115/60/1	4.80	4.70	4.55	4.30					15	15	4.80	4.10	3.20	2.30	1.30	.30	27.5
2807CE72*	1	115/60/1	6.60	6.40	6.20	5.90	5.13	4.35	3.75	3.05	50	120	6.60	3.60	2.66	1.80	.88		25.0

Oil-less Diaphragm Air Compressors and Vacuum Pumps

MODEL NUMBER	NOMINAL HP	VOLTAGE/ HERTZ/ PHASE	COMPRESSOR PERFORMANCE PSI VS. CFM								MAX. PRESS. PSI		VACUUM PERFORMANCE IN. HG VS. CFM						MAX. VACUUM IN. HG
			0	5	10	15	20	25	30	35	CONT.	INT.	0	5	10	15	20	25	
007CDC19	1/32	12V DC	.65	61	50	.41	.32	24			15	25	65	48	34	21			23.0
007BDC19	1/32	12V DC											1 26	90	58	.34			23.0
007CA13*	1/30	115/60/1	.61	.45	.31	.21	.14				15	20	.61	38	23	11			20.3
107CA18*	1/20	115/60/1	.76	.62	.51	42	34	27	20	12	25	35	76	58	40	23	08		23.2
107CDC20*	1/10	12V DC	1.20	1 00	81	.67	54	.45	.38	.28	20	35	1.20	.86	62	41			22.9
727CM39*	1/4	115/60/1	3 10	2.95	2 70	2.50	2.33	2.10	1 90	1 70	20	35	3 10	1 72	1 27	87	48		25.7
905CA18	1/15	115/60/1	1.40	1.13	.95	74	58	.41	25	.13	20	20	1 40	87	55	.32	.09		22.4
907CDC18*	1/10	12V DC	2.18	1.27	1.03	.83	.67				10	15	2 18	1.06	64	41			22.2
917CA18*	1/8	115/60/1	1.49	1.17	1 02	84	71	54	.44	.35	30	35	1 49	.89	.64	36	16		23.8
2107CA20	1/20	115/60/1	1.65	1.33							5	5	1 65	1 15	77	47	.17		23 2
2107CE18	1/20	115/60/1	1.50	1.24	1.05	.86	.68	50	32		20	25	1 50	1 10	75	41	.13		22 6
2107VA20	1/20	115/60/1											.85	65	49	33	20		28 2
2737CM390*	1/2	115/60/1	6.20	5.90	5.50	5.10	4.70				15	20	6 20	4 30	2 90	1.80	97		25.3
2737VM390	1/2	115/60/1											3 10	2 40	1 90	1.40	89	.34	29.0

Oil-less Linear Air Compressors

MODEL NUMBER	VOLTAGE/ HERTZ/ PHASE	COMPRESSOR PERFORMANCE PSI VS. CFM							COMPRESSOR PERFORMANCE PSI VS. AMPS							COMPRESSOR PERFORMANCE PSI VS. WATTS						
		0	1	2	3	4	5	6	0	1	2	3	4	5	6	0	1	2	3	4	5	6
5020V	115/60/1	1.16	.96	.66	.37	14			.27	.29	.30	.28	.28			16	17	15	13	10		
5030V	115/60/1	1.81	1.56	1.18	74	21			.70	.66	.62	.57	54			31	30	27	22	14		
5040V	115/60/1	2.09	1 86	1 51	1 12	61			91	87	.83	78	73			41	40	36	31	24		
5060V	115/60/1	2.70	2.54	2.23	1 89	1.55	1 10	69	1 47	1.43	1.36	1.29	1.22	1 16	1 12	64	62	60	55	50	42	30
5070V	115/60/1	3.04	2.89	2 59	2 25	1.87	1 46	99	1 94	1 91	1 85	1 77	1 70	1 64	1 57	84	82	78	73	68	61	51
5100	115/60/1	3.62	4.22	3.65	3.02	2.35	1.41	62	2 57	2.75	2 60	2.45	2 35	2.23	2 18	107	111	108	98	88	70	50
5120	115/60/1	4.03	4.80	4.23	3.40	2.90	2.00	1.40	2.38	3.08	2.91	2.75	2.62	2.55	2.41	121	127	124	114	104	88	72

✲ DISTRIBUTOR STOCK

The information presented in this material is based on technical data and test results of nominal units. It is believed to be accurate and reliable and is offered as an aid to help in the selection of Thomas products. It is the responsibility of the user to determine the suitability of the product for his intended use and the user assumes all risk and liability whatsoever in connection therewith. Thomas Industries does not warrant, guarantee or assume any obligation or liability in connection with this information.

PNEUMOTIVE OEM AIR COMPRESSORS

Taskair and SR Rotary Air Compressors and Vacuum Pumps

When an air source is required for operation at less than 15 PSIG, Taskair Rotary units provide for maximum air delivery with minimum physical size. The time-proven rotary vane pump design with integral drive motor combines to provide a high efficiency pneumatic power supply in a very compact configuration. In addition, when applied as a vacuum pump, Taskair rotaries can also provide efficient operation at continuous duty vacuum levels up to 27.0″ Hg. and maximum air flows at lower vacuum levels.

Oil-less design prevents oil mist or vapors in delivered air and provides for long-life.

Self-lubricating, self-adjusting vanes insure vane sealing for maximum efficiency and sustain pump capacity throughout service life.

Cast iron pump housing provides optimum running surface for vanes and long-life durability.

Precision machined surfaces provide close tolerance alignment of moving parts for peak performance and insure smooth running surface for vanes.

Permanently lubricated and sealed motor bearings contribute to overall "oil-less" operation for long, service-free life.

Taskair, GH and HP Piston Air Compressors and Vacuum Pumps

When your application requires an air source to operate at pressures greater than 15 PSIG, you need the performance of our Taskair, GH and HP piston models. SGH models are separate drive. With continuous duty pressure ratings to 175 PSIG, the integral motor and compressor design offers a truly reliable power supply for pneumatic control and actuation. Also, piston vacuum pump designs are available up to 1½ HP, which provide cool, efficient operation at high continuous duty vacuum levels up to 27.5″ Hg.

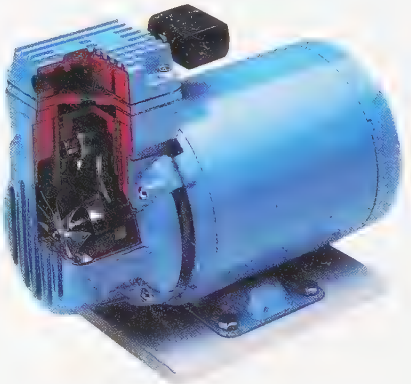
Oil-less design prevents oil mist or vapors in delivered air, and provides for long-life.

High strength, low lift stainless steel valves insure maximum efficiency and provide reliable operation.

Cast iron cylinders provide optimum running surface for piston rings and skirts and long-life durability.

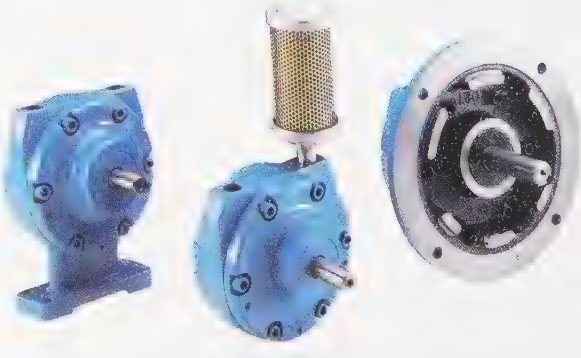
Teflon® piston rings and skirts provide effective seal for optimum volumetric efficiency and to insure low piston friction.

Permanently lubricated and sealed bearings contribute to overall "oil-less" operation for long, service-free life.



ROTARY VANE AIR MOTORS

From 1/3 to 5 HP, Pneumotive rotary vane air motors provide reliable power for hundreds of demanding OEM and industrial applications. These compact and lightweight models (2-28 lbs.) feature variable speed operation from 300-10,000 RPM. Interchangeable with most competitive models, Pneumotive rotary vane air motors can operate in any position and are available in four mounts: hub mount, face mount, base mount, and NEMA mount.



AND VACUUM PUMPS

THOMAS
INDUSTRIES INC.

TASKAIR—Rotary Vane Air Compressors and Vacuum Pumps

MODEL NUMBER	NOMINAL HP	VOLTAGE/ HERTZ/ PHASE	FRAME	COMPRESSOR PERFORMANCE PSIG VS. CFM				MAX. PRESS. PSIG		VACUUM PERFORMANCE IN. HG VS. CFM						MAX. VACUUM IN. HG
				0	5	10	15	CONT.	INT.	0	5	10	15	20	25	
SR-0015-VP	1/10	115/50/60/1		1.50	1.20	.95	.75	10	10	1.50	1.19	.88	.56	.25	0	24.0
SR-0015-VP	1/10	115/50/60/1		1.50	1.20	.95	.75	10	10	1.50	1.14	.88	.56	.25	0	24.0
SR-0030	1/6	115/60/1		2.85	2.58	2.30	2.04	10	10	2.85	2.26	1.66	1.07	.48	0	24.0
TA-0015-P	1/8	115/50/60/1	48	1.95	1.60	1.15	.60	15	15							
TA-0030-P	1/4	115/50/60/1	48	3.00	2.40	1.80	1.20	15	15							
TA-0040-P	1/3	115/50/60/1	48	4.00	3.60	3.20	2.80	15	15							
TA-0075-P	1/2	115/230/60/1	56	7.20	6.70	6.20	5.70	10	15							
TA-0100-P	3/4	115/230/60/1	56	10.00	9.50	9.00		10	10							
TA-0170-P	1½	115/230/60/1	Close Coupled Rotary	17.00	14.50	12.50	11.00	15	15							
TA-0210-P	2	208/230/460/60/3	Close Coupled Rotary	21.00	19.50	17.90	16.20	15	15							
TA-0015-V	1/8	115/50/60/1	48							1.85	1.45	1.05	.64	.24	0	23.0
TA-0030-V	1/6	115/50/60/1	48							3.00	2.38	1.75	1.13	.50	0	24.0
TA-0040-V	1/4	115/50/60/1	48							4.00	3.23	2.46	1.69	.92	.15	26.0
TA-0075-V	1/2	115/230/60/1	56							7.20	5.82	4.43	3.05	1.66	.28	26.0
TA-0100-V	3/4	115/230/60/1	56							10.00	8.08	6.15	4.73	2.31	.38	26.0
TA-0170-V	1	115/230/60/1	Close Coupled Rotary							17.00	13.85	10.70	7.56	4.41	1.26	27.0
TA-0210-V	1½	115/230/60/1	Close Coupled Rotary							21.00	17.11	13.22	9.33	5.41	1.56	27.0

TASKAIR, GH, and HP—Piston Air Compressors and Vacuum Pumps

MODEL NUMBER	NOM. HP	# OF CYL.	VOLTAGE/ HERTZ/ PHASE	FRAME	COMPRESSOR PERFORMANCE PSIG VS. CFM										MAX. PRESS. PSIG		VACUUM PERFORMANCE IN. HG VS. CFM						MAX. VACUUM IN. HG
					0	10	20	40	60	80	100	125	150	175	CONT.	INT.	0	5	10	15	20	25	
LGH-106	1/12	1	115/50/60/1	48	1.20	.95	.75	.40	0						60								
TA-1061	1/12	1	115/50/60/1	48	1.20	.95	.75	40	0						60	—							
LGH-210	1/6	1	115/50/60/1	48	1.40	1.25	1.10	80	.60	.45	.35				100	—							
TA-2051	1/6	1	115/50/60/1	48	1.60	1.40	1.20	1.00	.90						50	—							
TA-2101	1/6	1	115/50/60/1	48	1.40	1.25	1.10	.80	.60	.45	.35				100	—							
TA-2101-D	1/6	1	12V-DC		1.40	1.25	1.10	.80	.60	.45	.35				100	—							
LGH-305	1/4	1	115/230/60/1	48	1.80	1.65	1.50	1.20	1.00						50	—							
LGH-310	1/4	1	115/230/60/1	48	1.60	1.50	1.40	1.20	1.00	.80	.60				100	—							
GH-3051B	1/4	1	115/230/60/1	56	2.00	1.85	1.70	1.50	1.30						50	—							
GH-3101B	1/4	1	115/230/60/1	56	1.70	1.55	1.40	1.20	1.00	.85	.75				100	—							
TA-3051	1/4	1	115/230/60/1	48	2.00	1.85	1.70	1.50	1.30						50	—							
TA-3101	1/4	1	115/230/60/1	48	1.70	1.55	1.40	1.20	1.00	.85	.75				100	—							
TA-3101-DC	1/4	1	12V-DC		1.70	1.55	1.40	1.20	1.00	.85	.75				100	—							
TA-4051	1/3	1	115/60/1	48	2.80	2.65	2.45	2.10	1.80						50	—							
TA-4101	1/3	1	115/60/1	48	2.20	2.05	1.90	1.65	1.45	1.25	1.10				100	—							
TA-4101-DC	1/3	1	12V-DC		2.20	1.95	1.75	1.45	1.25	1.10	.95				100	—							
GH-3052B	1/4	2	115/230/60/1	56	2.50	2.30	2.10	1.80	1.55						50	—							
TA-3052	1/4	2	115/230/60/1	56	2.50	2.30	2.10	1.80	1.55						50	—							
GH-405B	1/3	2	115/230/60/1	56	3.30	3.05	2.80	2.40	2.00						50	—							
GH-410B	1/3	2	115/230/60/1	56	2.60	2.40	2.20	1.80	1.60	1.35	1.20				100	—							
GH-417B	1/3	2	115/230/60/1	56	1.40	1.38	1.35	1.30	1.25	1.20	1.15	1.10	1.05	1.00	175	—							
TA-4052	1/3	2	115/230/60/1	56	3.30	3.05	2.80	2.40	2.00						50	—							
GH-505B	1/2	2	115/230/60/1	56	4.30	4.05	3.75	3.30	2.95						50								
GH-510B	1/2	2	115/230/60/1	56	3.20	3.00	2.80	2.40	2.10	1.90	1.70				100	—							
GH-517B	1/2	2	115/230/60/1	56	1.80	1.79	1.78	1.75	1.72	1.69	1.65	1.60	1.55	1.50	175	—							
TA-5052	1/2	2	115/230/60/1	56	4.30	4.05	3.75	3.30	2.95						50	—							
TA-5102	1/2	2	115/230/60/1	56	3.20	3.00	2.80	2.40	2.10	1.90	1.70				100	—							
GH-605B	3/4	2	115/230/60/1	56	5.20	4.90	4.65	4.25	3.95						50	—							
GH-610B	3/4	2	115/230/60/1	56	4.30	4.05	3.80	3.30	3.10	2.80	2.50				100	—							
GH-617B	3/4	2	115/230/60/1	56	2.40	2.39	2.37	2.34	2.31	2.28	2.25	2.20	2.15	2.10	175	—							
TA-6052	3/4	2	115/230/60/1	56	5.20	4.90	4.65	4.25	3.95						50	—							
TA-6102	3/4	2	115/230/60/1	56	4.30	4.05	3.80	3.40	3.10	2.80	2.50				100	—							
TA-7102	1	2	115/230/60/1	56	5.40	5.20	5.00	4.60	4.20	3.75	3.30				100	—							
HP-1050	1	2	115/230/60/1	56	9.80	8.75	7.60	6.40	5.60						50	—							
HP-1000	1	2	115/230/60/1	56	7.50	6.90	6.40	5.20	4.40	3.70	3.30	2.90			125	145							
HP-1550	1½	2	115/230/60/1	56	10.40	9.70	8.90	8.00	7.40						50	—							
HP-1500	1½	2	115/230/60/1	56	10.00	9.30	8.60	7.50	6.70	5.90	5.20	4.60			125	145							
LGH-1V	1/12	1	115/50/60/1	48													1.35	1.09	.83	.57	.31	.05	26.0
TA-1V1	1/12	1	115/50/60/1	48													1.35	1.09	.83	.57	31	.05	26.0
LGH-2V	1/6	1	115/50/60/1	48													2.15	1.76	1.37	.98	.59	.20	27.5
TA-2V1	1/6	1	115/50/60/1	48													2.15	1.76	1.37	.98	.59	20	27.5
TA-3V2	1/4	2	115/230/60/1	56													3.60	2.95	2.29	1.64	.98	.33	27.5
GH-3V1B	1/4	1	115/230/60/1	56													1.70	1.39	1.08	.77	.46	.15	27.5
GH-3V2B	1/4	2	115/230/50/1	56													3.10	2.54	1.97	1.41	.85	.28	27.5
GH-4VB	1/3	2	115/230/60/1	56													3.60	2.95	2.29	1.64	.98	.33	27.5
TA-4V2	1/3	2	115/230/60/1	56													4.20	3.44	2.67	1.91	1.15	.38	27.5
GH-5VB	1/2	2	115/230/60/1	56													4.20	3.44	2.67	1.91	1.15	.38	27.5
HP-100V	1	2	115/230/60/1	56													8.00	6.55	5.09	3.64	2.18	.73	27.5

To receive more information on the following Thomas products, call or write Thomas Industries Inc.

The Power Air Division of Thomas Industries Inc. is located in Sheboygan, Wisconsin.

The Pneumotive Division is Thomas Industries Inc. is located in Monroe, Louisiana.

THOMAS
INDUSTRIES INC.
POWER AIR DIVISION
1419 Illinois Avenue
Sheboygan, WI 53081
414-457-4891
FAX 414-457-2389

AIR COMPRESSORS & VACUUM PUMPS

OEM Catalog and Selection Guide

THOMAS

Circle 483

Power Air OEM Catalog for Piston, Diaphragm, and Linear Air Compressors and Vacuum Pumps
Form # 850-1196

PNEUMOTIVE AIR COMPRESSORS & VACUUM PUMPS

OEM Catalog and Selection Guide

THOMAS

Circle 484

Pneumotive OEM Catalog for Piston and Rotary Vane Air Compressors and Vacuum Pumps
Form # 850-1117

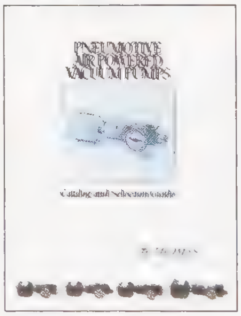
PNEUMOTIVE AIR MOTORS

Catalog and Selection Guide

THOMAS

Circle 485

Pneumotive Air Motor Catalog
Form # 850-1211



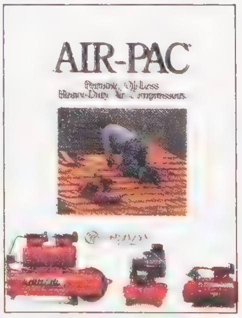
PNEUMOTIVE AIR POWERED VACUUM PUMPS

Catalog and Selection Guide

THOMAS

Circle 486

Pneumotive Air-Powered Vacuum Pump Catalog
Form # 850-1262



AIR-PAC

Portable, Oil-Less Heavy-Duty Air Compressors

THOMAS

Circle 487

Power Air Air-Pac® Portable, Heavy-Duty Air Compressors
Form # 850-1186

SPRAYIT

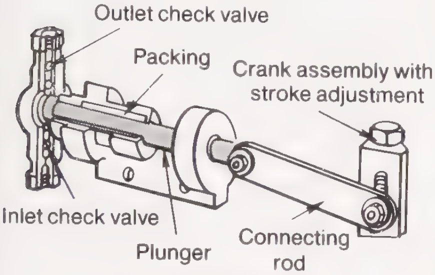
Variable Duty Spray Guns, Compressors & Vacuum Pumps

THOMAS

Circle 488

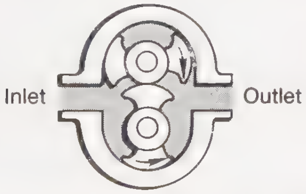
Power Air Sprayit® Compressors, Sprayers, and Spray Guns
Form # 850-1092D

Plunger or piston pumps are one type of commonly used positive-displacement pump. They usually consist of one or more pistons that draw fluid through an inlet check valve and expel it through an outlet valve. Fluid volume delivered depends on plunger diameter and stroke length; diameter cannot be varied in a given pump, so stroke length is made adjustable. Most plunger pumps must be stopped for stroke adjustment, but a few offer the option of in-service adjustment. Outlet pressures delivered by plunger pumps are as high as 50,000 psi for some lab units. Maximum pressures for industrial pumps usually range from 5,000 to 30,000 psi. Maximum flow is as high as 26 gpm for traditional plunger pumps and much higher for multipiston units.



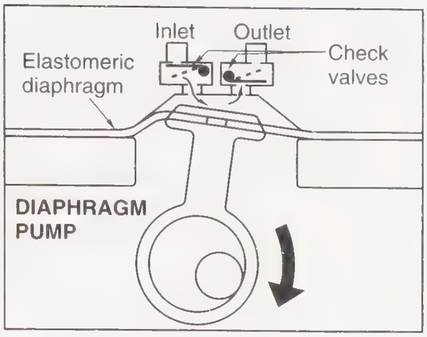
PLUNGER PUMP

Circumferential-piston pumps use counterrotating rotors driven by external timing gears. They are self-priming and have high suction lift capability. With capacities up to 450 gpm, the pumps are often used for shear-sensitive fluids, or those with entrained particles or gases.



CIRCUMFERENTIAL-PISTON PUMP

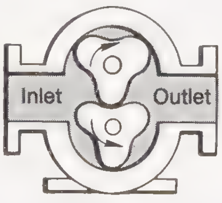
Diaphragm and bellows pumps are used when pump leakage or process-fluid contamination cannot be tolerated. They offer the freedom from external leakage of a peristaltic pump, yet permit higher pressures and easy flow adjustment. Of course, they tend to cost more than peristaltic pumps for the same flow delivered. Generally, diaphragm pumps are built like a plunger unit, except that a bellows or diaphragm is fitted to the end of the plunger shaft. This configuration, while providing a positive seal, stresses the diaphragm because of unequal loading from the plunger. To equalize diaphragm loading, some pumps are built so the plunger never contacts the diaphragm; instead, the plunger pressurizes a small volume of hydraulic fluid as it moves, and the fluid displaces the diaphragm. Diaphragm pumps of this type can deliver outlet pressures to 5,000 psi.



DIAPHRAGM PUMP

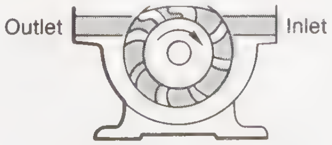
Gear pumps, often used in fluid-power applications, perform equally as well as fluid-handling pumps. The gears can be arranged as a pair of similarly sized gears, as three stacked gears, as separated internal gears, or as gerotors. Displacement of gear pumps is fixed, and cannot be varied during operation.

Lobed pumps resemble gear pumps. Motion of the rotors creates an expanding cavity on the inlet side, a constant-volume cavity that carries fluid to the outlet side, and a contracting cavity that forces fluid out. In some models, rotors are driven by external timing gears to avoid rotor contact in the fluid stream. Lobed pumps have relatively large displacement, so they are often used for shear-sensitive fluids, as well as fluids with entrained gases or particles.



LOBED PUMP

Flexible-vane pumps are similar to sliding-vane hydraulic pumps, but they substitute flexible elastomeric vanes for rigid vanes. These relatively inexpensive pumps pass medium solids and are easy to maintain in the field. Flexible-impeller pumps usually operate at discharge pressures of 20 to 30 psi. High-pressure blades with thicker cross sections boost operating pressure to about 60 psi. However, high-pressure impellers fatigue more rapidly because higher stresses develop when flexing. Operating temperature is limited to about 180°F.

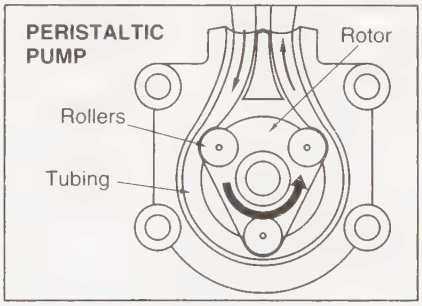


FLEXIBLE VALVE PUMP

Nutating pumps have a disc, held between two plates, that wobbles without rotating and creates line contact with both plates. As the contact lines pass the inlet port, liquid is pulled into the cavities between the disc and plates. The fluid, then, is swept through the pump to the discharge port (much as a squeegee wipes water from a window) where it is released under pressure. A so-called bridge separates inlet flow from outlet flow.

Nutating action provides a number of operating benefits. The pumps are self-priming from 6 in. when dry and 21 ft when wet. Also, because pump parts do not rotate, a bellows seal can be used on the shaft in place of a mechanical face or lip seal, providing longer seal life. Finally, the disc excursion flattens to relieve excessive pressure, bypassing flow and preventing damage to the pump parts. This feature eliminates the need for a separate pressure relief valve in the system.

Peristaltic pumps consist of a flexible tube that is progressively compressed by a series of rollers. As the rollers move along the tube, they force fluid through it. A chief advantage of these pumps is freedom from external leakage. Fluid is contained within the tube, and can leak only if the tube ruptures. Peristaltic pumps are simple and quite inexpensive for the flow rates they provide.



PERISTALTIC PUMP

Displacement is determined by tube size, so delivery rate can only be changed during operation by varying pump speed. However, some models have an adjustable track height, so flow rate can be changed by stopping the pump, changing tubes, adjusting track height, and restarting the pump.

Two-roller pumps do a relatively poor job of drawing liquid into the pump, and often require gravity feed or a pressurized intake. However, three-roller pumps are said to pull a vacuum of 28-in. Hg when equipped with tubing that has a hardness of 60 Shore A.

Most pumps permit a maximum outlet pressure of only 50 psi or less. Two-roller pumps provide flows as high as 3.5 gpm, but three-roller pumps providing flows up to 40 gpm are available.

Centrifugal pumps are a practical choice for fairly constant, large flows of over 100 gpm at moderate pressures and low fluid viscosities. The first step in selecting a centrifugal pump is to determine application requirements: quantity of flow, pressure rise (or change in head) in ft of fluid, and other conditions such as high fluid viscosity or temperature.

After operating requirements have been set, specific speed, N_s, should be determined. Specific speed is a characteristic quantity used to describe a centrifugal pump, and is found from:

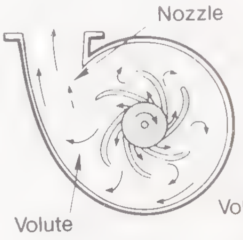
$$N_s = NQ^{1/2} / h^{3/4}$$

where N = impeller speed, rpm; Q = flow rate, gpm; and h = net positive suction head, ft. The result is usually expressed as a dimensionless number.

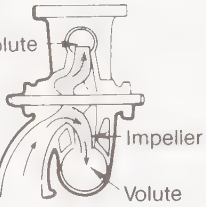
If the required specific speed falls between 500 and 15,000, a volute, diffuser, or propeller pump becomes the best selection. If specific speed is less than 500, a peripheral or even a positive-displacement pump should be considered. For a specific speed above 15,000, a parallel system of two or more pumps is usually necessary.

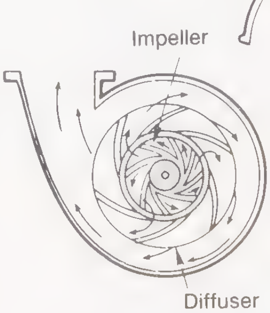
Within the limits of net positive suction head (NPSH) available, the pump with the highest specific speed is generally the best choice, because it operates at the highest rotational speed and is the smallest that can be used. (NPSH is the total of potential and kinetic energy heads in the fluid at the intake to a pump, minus fluid vapor pressure.)

Volute and diffuser pumps draw liquid into the impeller at its center and fling it outward by centrifugal force. The liquid leaves the impeller with higher pressure and velocity than when it entered. The velocity — especially its tangential component — is then partially transformed into additional pressure by the pump casing. The amount of energy transformed and efficiency of the transformation depend upon the shape of the casing.



VOLUTE PUMP-THE "BASIC" CENTRIFUGAL





DIFFUSER PUMP FOR HIGHER EFFICIENCY

In a volute pump, the impeller discharges the liquid into a "volute" — a channel of gradually increasing area. In a diffuser pump, stationary diffuser blades in the casing around the outside circumference of the impeller blades are curved in the opposite direction from the blades. The diffuser has less slippage and higher pump efficiency than the volute, but the additional blades increase complexity and cost.

Pump capabilities

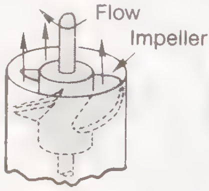
Type of pump	Maximum delivery (gpm)	Maximum pressure (psi)
Gear	5,000	4,500
Plunger	26	30,000
Peristaltic	40	50
Diaphragm	26	5,000
Bellows	0.6	35
Cammed vane	0.4	1,000

These are general capabilities within a class of pumps, not a description of a specific pump. Thus, there exists a gear pump that delivers 5,000 gpm, and another that delivers flow at 4,500 psi; but they are not the same pump.

Most single-stage horizontal pumps are built with volute casings. Diffusers are usually used in mixed and axial-flow vertical pumps, and in multistage pumps.

Propeller and mixed-flow pumps are commonly used at very high flow rates and low heads (above 300 gpm and below 40 ft); in this range, they provide more efficient pumping in a smaller package than volute or diffuser types.

Propeller pumps operate like a boat propeller encased in a tube. Liquid is drawn into the pump, parallel to the axis of the impeller, and is pushed out with no change in the direction of flow. Propeller pumps are available for vertical or horizontal operation, with specific speeds from 10,000 to 15,000. Suction characteristics of propeller pumps are not good, so intakes must be located below (or only slightly above) the surface of the liquid being pumped.



BASIC PROPELLER PUMP

MIXED-FLOW IMPELLER

How metering pumps stand up to common fluids

Type of fluid	Packed plunger	Hydraulically actuated disc diaphragm	Mechanically actuated disc diaphragm	Tubular diaphragm	Tubular/disc diaphragm	Double-tubular diaphragm	Double-disc diaphragm
Acid	P	E	E	G	E	G	G
Slurry	E	E	F	E	E	E	F
Viscous	E	E	F	E	E	E	F
Polymer	E	E	F	E	E	E	F
Adhesive	E	E	F	E	E	E	F
Grease	E	E	F	E	E	E	F
Oil	E	E	G	E	E	E	G
Synthetic	E	E	E	G	E	E	G
Liquefied gas	P	P	E	P	P	P	E
High-temperature	E	G	G	F	F	F	E
Hazardous	P	E	E	E	E	E	E
Radioactive	P	P	E	P	P	P	E*
Sterile	F	E	E	E	E	E	E

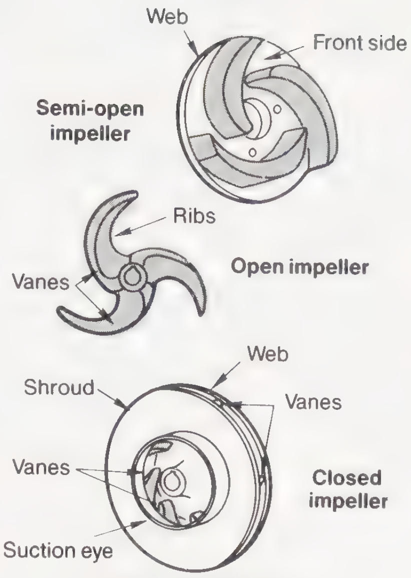
E-Excellent, G-Good, F-Fair, P-Poor; *Metallic diaphragm only.

Mixed-flow pumps can produce a larger range of heads than straight pumps. Because the rotors are similar to those in water turbines, this pump is often called a turbine pump. In a mixed-flow pump, the head is generated partly by propeller action and partly by centrifugal force in a volute casing. As with the propeller type, the mixed-flow pump can have only a single-section inlet. Thus, the mixed flow pump bridges the gap between the propeller and purely centrifugal types.

Peripheral pumps have circular, rotating impellers but provide characteristics similar to those of a positive-displacement pump. These low-volume, high-head pumps deliver 1 to 50 gpm and up to 500 ft of head discharge. They have excellent suction characteristics, drawing up to 28 ft of head. They are sometimes called turbine-vane, viscous-drag, or regenerative pumps. Peripheral pumps usually cost less than centrifugal or positive-displacement pumps, but often have a much shorter life.

Options often determine the usefulness and applicability of a centrifugal pump. Among the most important options are impeller type, number of stages, shaft positions, and suction intakes.

The impeller in a centrifugal pump can be open, semiopen, or closed. An open impeller consists of blades attached to a hub. A semiopen impeller has a circular plate, or inner shroud, on the inside of the blades. This may extend to the outer ends of the blades. The shroud supports the use of thinner blades. A closed impeller has an outer shroud (attached to the outer edge of the blades) as well as an inner one. Liquid is, thus, confined to the space between the shrouds. The confined passage reduces friction losses in the pump and thus increases efficiency.



IMPELLER OPTIONS

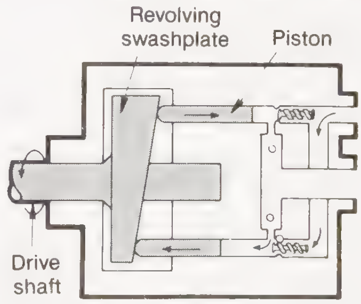
Staging is used to increase head or flow of centrifugal pumps. A two-stage pump is essentially two pumps in series — volume flow remains about the same, but output pressure is almost doubled. The impellers of a multistage pump are on the same shaft, and the housings are a single unit. Because liquid velocity can be kept high as it moves through the housing, a two-stage pump is more efficient than two single-stage pumps connected in series to produce the same head and volume.

Suction intake can also affect pump performance. An impeller can be designed for either single or double-suction operation. A double-suction impeller draws in liquid at both sides, so flow is almost twice that of a single-suction type for the same net positive suction head.

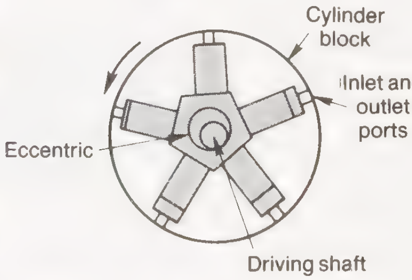
Hydraulic pumps

Most hydraulic pumps receive fluid from a reservoir and pump it to a loaded actuator in such a fashion that the actuator can perform work. The pumps may deliver flows of less than one to as much as 600 gpm. They are capable of withstanding output pressures in the range of 500 to about 15,000 psi.

Pressure: Pump pressure rating is one of the major considerations in determining whether it can do the job. Nearly all hydraulic pumps work in rotary fashion. As a pump rotates, it develops a partial vacuum on the inlet ("suction") side, permitting fluid under atmospheric pressure in the reservoir to flow into the pump inlet. Then the pump ejects this fluid, usually at a pressure higher than atmospheric. It is worth noting that a pump does not create pressure. It merely moves fluid, causing the flow. Pressure is created by the load on the fluid; if no load exists, the fluid has very little pressure. As the load is placed on the fluid, the pressure at the outlet side of the pump increases to a value that is normally indicated as the pump maximum. Therefore, a 3,000-psi pump is a unit that can maintain flow against a load of 3,000 psi.

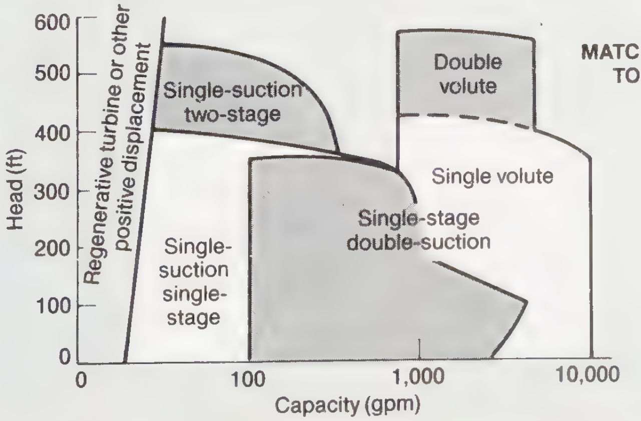


CHECK VALVE AXIAL-PISTON PUMP



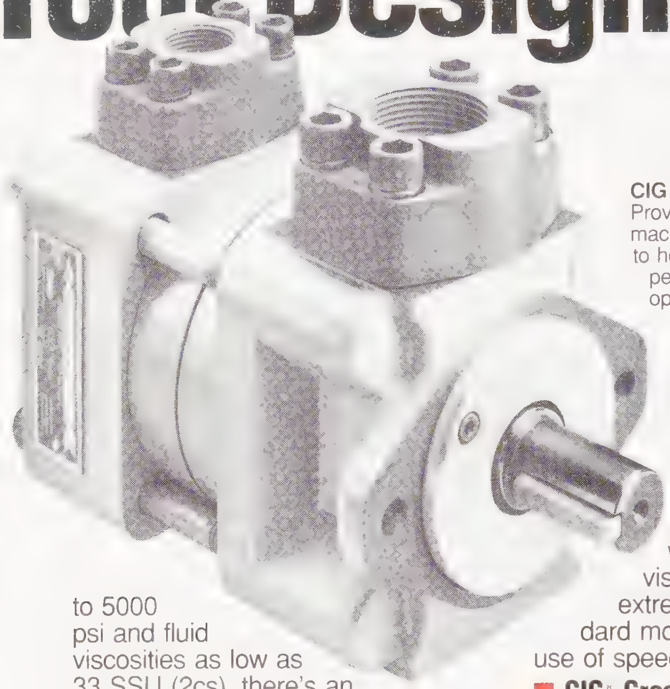
CHECK VALVE RADIAL-PISTON PUMP

Pump pressure rating is generally limited by the capability of the pump to withstand pressure without undesirable increase in internal leakage, and without damage to the pump parts. Although many pumps can withstand pressures within the very wide range of 500 to 15,000 psi, ratings for maximum continuous service are often



MATCH THE PUMP TO THE JOB

Make The Most Of Your Designs.



CIGᴿ **Crescent Internal Gear.** Provide extended life for machinery applications exposed to heat or requiring precision performance and low noise operation. Available in over 1400 performance combinations.

You can build top performance and long-term reliability into your fluid handling systems when you specify a Positive Displacement Pump from IMO.

We offer a wide selection of positive displacement pumps for the most demanding high performance applications. In both rotary screw and crescent internal gear designs, IMOᴿ pumps will give you the long lasting pumping reliability and efficiency you need for your toughest fluid handling or fluid power jobs. At flows from one to 3500 gpm, pressures from 25 to 5000 psi and fluid viscosities as low as 33 SSU (2cs), there's an IMO model to fit any high performance requirement — whether it's providing uninterrupted fuel oil service to turbines or precision testing jet aircraft engine components. All are precision manufactured and backed with our more than 50 years of experience in high performance pumping.

■ IMOᴿ Rotary Screw Pumps

The unique IMO three-screw rotary design features only three moving parts and no wearing contact. This simplicity assures high reliability, maximum pumping efficiency and extended pump life with only minimal maintenance. The IMO pump produces non-pulsating flows against varying pressures over a very wide range of fluid viscosities. Operation is extremely quiet and at standard motor speeds without the use of speed reduction gears.

■ CIGᴿ Crescent Internal Gear Pumps

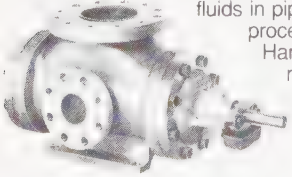
Designed for quiet, long lasting, low lubricity operation, the CIG has a life of up to 30,000 hours — 10 times longer than piston, vane or standard gear pumps. Its noise level is typically 68 db (A) compared to these conventional designs usually operating at 90 db (A). With ultra-low pressure ripple (0.62% @ 4500 psi), the CIG produces a smooth, constant flow for precision applications. Compact, modular construction permits multi-staging and multi-pump applications to increase pressures or flows in single circuits or to power multiple circuits.

Series 4U, 6U. Compact design for hydraulic, lubricating and seal oil applications. Efficient for machining center cooling systems. Flow direction can be reversed for use as a hydraulic motor.

Series 3D, 6D, 12D. Handle wide range of heavy-duty lubrication, circulation and process applications. Available with optional I-MAG™ Magnetic Drive Couplings.

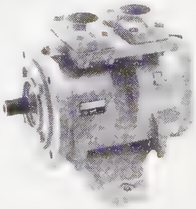
Series 3E. Ideal for lube oils, fuel oils, hydraulic fluids and cutting fluids. Low 75 dbA noise level. Four simple mounting options increase versatility.

Series 323F, 324A. Designed for pumping high volumes of viscous and shear sensitive fluids in pipelines and process systems. Handle high flow requirements.



Series 110H/210H. Compact design permits fast installation. Inlet head rotates in 90° increments to meet existing or new piping requirements. Flow direction can be reversed for use as a hydraulic motor.

Series ACE, UCG, UCF. Complete family of three-screw rotary pumps with integral relief valves. Apply advantages of the IMO design to traditional integral relief valve applications.



IMO

IMO offers a wide selection of high performance pumps for many demanding applications.

- Fluid Power
- Hydraulic Sealing
- Lube Oil Service
- Fuel Oil Service
- Fluid Process/Transfer

IMO

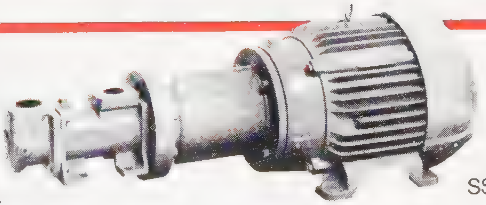
Series	Application					Special Features		Specifications							Number of Sizes
	Process/ Transfer	Fuel Oil Service	Lube Oil Service	Hydraulic Sealing	Fluid Power	Integral Relief Valve	Magnetic Drive Coupling*	Flow Range		Maximum Discharge Pressure		Maximum Speed	Maximum Power		
								US GPM	L/MIN	PSIG	BAR-G	RPM	HP	KW	
								IMO® ROTARY SCREW PUMPS							
3E	•	•	•				•	1-100	4-375	150	10	8000	20	15	10
110H	•				•			2-7	7-25	1500	100	5000	10	7.5	2
210H	•	•			•			7-16	25-60	2000	140	5000	30	22	4
3D	•	•	•	•	•		•	5-400	20-1500	500	35	5000	150	110	11
6D	•	•		•			•	5-400	20-1500	1500	100	5000	300	225	12
12D	•	•		•			•	5-250	20-950	2200	150	5000	350	260	10
ACE			•			•		4-44	16-176	150	10	4000	10	7.5	5
UCG	•		•			•		30-280	110-1060	250	18	4000	75	56	4
UCF	•		•			•		120-800	480-3200	175	12	2000	150	110	7
4U					•			15-175	55-660	2000	140	4400	300	225	7
6U					•			15-175	55-660	3000	200	4400	450	335	8
323F	•	•	•					400-3500	1500-13,250	300	20	1500	775	575	4
324A	•	•	•	•				50-900	200-3400	500	35	4200	350	260	10
								CIG® CRESCENT INTERNAL GEAR PUMPS							
CIG-2		•			•			1-7	4-26	5000	333	9000	52	—	6
CIG-3		•			•			2-30	8-114	5000	333	7200	82	—	6
CIG-4		•			•			3-48	11-182	5000	333	5700	130	—	6
CIG-5		•			•			6-75	23-284	5000	333	4500	207	—	6
CIG-6		•			•			10-118	38-447	5000	333	3600	329	—	6
CIG-8		•			•			17-122	64-462	5000	333	3000	500	—	6

*Optional

All capabilities are not available on all pumps. Consult your local IMO Pump Division office or representative for detailed information. Special and custom designs are invited.

I-MAG™ Magnetic Drive Couplings

Permit leak-proof, low-maintenance pumping of non-corrosive fluids with all of the advantages of the IMO rotary screw pump design.



IMO® Model A3D with 15 hp Magnetic drive and TEFC motor, 15 gpm, 300 psig discharge, 9600 SSU, 1200 rpm.

- Four coupling sizes for use with IMO 3D, 6D and 12D Series Pumps.
- Handle flow rates from 5 to 425 gpm at pressures to 2200 psi and speeds to 3600 rpm.
- Elimination of dynamic seals minimizes maintenance and replacement costs associated with shaft seals.
- Hydraulically balanced elements eliminate the need for thrust plates or additional bearings.
- Available in either C-face or frame mounted configurations.
- Proven low noise design.

For More Information:

To find out more about these or other IMO pump models, call us at IMO Pump Division (in Europe: IMO AB, Stockholm, Sweden). And let us help you make the most of your designs.

IMO
Imo Industries Inc.

IMO Pump Division
P. O. Box 5020
Monroe, NC 28111-5020
704-289-6511
FAX: 704-289-9273

clustered in the 2,000 to 4,000-psi range. Typically, maximum pressure for external gear and vane pumps are from 2,000 to 4,000 psi. Internal-gear units run somewhat lower, with maximums in the range of 1,500 to 2,000 psi. Most piston pumps are designed for a maximum rating of 3,000 psi, although some are suitable for 5,000-psi service. A few permit higher pressures for intermittent peak loads

Flow: The second most important consideration in selecting a pump is its size and delivery. Size is usually expressed as volumetric flow output (gpm). Other words with the same meaning are flow, size, capacity, or delivery rate.

Flow rating of a pump is based on performance under a specific set of conditions. For example, pumps used in mobile applications are generally tested at 1,200 rpm, at an outlet pressure of 100 psi and atmospheric inlet pressure. Typically, manufacturer's literature states the conditions under which the rating is made.

Speed: A third consideration is the speed rating, which may be limited by the ability of the pump to fill without cavitating or by other mechanical considerations. The permissible speed range and inlet pressure requirements for any design are usually clearly defined.

Efficiency: Pump quality is rated in efficiency, with three efficiency ratings commonly given.

- *Volumetric efficiency* is the ratio of actual to theoretical delivery. Difference between actual and theoretical delivery is normally due to internal leakage necessary to lubricate the pump (called "slippage") and other factors. Volumetric efficiency is typically very high, often in the mid to high 90s.
- *Overall efficiency* is the ratio of hydraulic power output to mechanical power input.
- *Mechanical efficiency* is the ratio of overall efficiency to volumetric efficiency. Mechanical losses are due principally to internal friction, and fluid compression.

Fluid compatibility: For years, petroleum oils have been the "standard" hydraulic fluid used in power circuits. This situation remains today, but is changing as safety considerations and government compliance agencies force greater acceptance of fire-resistant hydraulic fluids.

Most pumps used today were designed for petroleum fluids — oil — and nearly all worked well with them. When other fluids are used in these pumps, some suffer. Accordingly, a pump must be specially selected to operate with special fluids. Certain types of pumps do not work well with some hydraulic fluids.

Even when pump and fluid are basically compatible, pump seals must often be changed for compatibility with the other fluid. In addition, stability characteristics of fire-resistant fluids are often different than those of hydraulic oils. Different system operating

SORTING THROUGH PUMPS AND LIQUIDS

A centrifugal pump has to be compatible with numerous liquids. These unusual liquids may be highly acidic or highly alkaline; ultrapure or highly abrasive. There is a variety of material combinations and pump designs available to meet the needs of any liquid.

Corrosives: Corrosion-resistant pumps are built at reasonable cost from many alloys and plastics. Stainless-steel and reinforced-plastic pumps can withstand corrosive effects of both highly alkaline and highly acidic liquids. In magnetic-drive pumps, the drive shaft of the power source does not enter the pumping chamber, eliminating the need for exotic seals to prevent leakage or contamination.

Sanitary liquids: Besides excellent corrosion resistance, pumps made of 316 stainless steel provide sanitary handling of products in the food, dairy, pharmaceutical, and cosmetic industries. In such pumps, all parts in contact with the pumped product are made of 316 stainless steel. The pump interior and exterior also have a minimum #4 finish to permit easy cleaning.

Typically, sanitary pumps are designed to facilitate routine cleaning. Some sanitary pumps also provide clean-in-place capabilities, in which the equipment is cleaned by circulating cleaning solution through the pump and lines rather than being taken apart and hand washed. Because they are "self-cleaning," such pumps greatly reduce cleanup time.

Entrained solids: In many pumps, the impeller includes a web or shroud that encloses the vanes on both sides. These are called closed impellers and are relatively efficient in conveying liquid from the inlet to the outlet because they minimize losses from friction and turbulence. However, they cannot be used when the pumped liquid contains particles that might bridge across the vanes inside the web, blocking flow.

Semiopen impellers, on the other hand, have no shroud, permitting moderately sized solid particles to be conveyed with the liquid. Open impellers, where both front and back webs are omitted, handle larger solid particles and higher particle concentrations without clogging.

Generally, the velocity imparted to liquids in centrifugal pumps means that they cannot convey delicate solids in suspension or shear-sensitive liquids without damaging the particles or changing liquid consistency. In addition, air-entrained liquids, including foams, break the vacuum needed for pumping. Even small amounts of air at the impeller inlet can interrupt the pumping action.

Heavy liquids: The horsepower required to run a centrifugal pump at a specific head and flow depends on the specific gravity of the pumped liquid. All head-vs.-flow curves published by manufacturers are based on water; therefore, the horsepower required to pump a higher specific-gravity liquid must be adjusted accordingly. The relationship is $H_r = H_w S_g$, where H_r = required horsepower, H_w = horsepower based on water flow, and S_g = specific gravity.

In some installations, a fixed-horsepower pump can handle a higher specific gravity liquid if the discharge line is restricted. In this way, the pump operates against a higher back pressure, which reduces pump capacity and, thus, required drive horsepower. In effect, less power is needed to handle the reduced flow, so more power is available to accelerate the heavier liquid. This technique is useful, however, only when reduced flow capacity is acceptable.

Viscous liquids: Centrifugal pumps handle liquids with viscosities as high as 1,500 SSU with minimal performance degradation; however, the pumps are not normally recommended for liquids with higher viscosities. The higher the viscosity, the greater the resistance to flow; thus, pumps handling viscous liquids require higher horsepower. In addition, high viscosity reduces capacity, head, and pumping efficiency.

GEAR PUMPS

Gear pumps are compact, inexpensive devices that feature few moving parts. A number of internal and external gear types have evolved to meet a wide variety of applications.

Gear-on-gear pumps consist of two gears, usually of equal size, that mesh with each other inside a housing. The driving gear is an extension of the drive shaft; as it rotates, it drives the second gear. As the gears rotate within the housing, fluid is swept from the inlet to the outlet. These gears must carry the full power load of the pump, and they are highly stressed at high pressures and high loads. Gears of either spur or helical configuration can be used with spur gears being the most common.

Volume of fluid pumped through a gear pump depends on the depth of the tooth and the width of the gear. The greatest output occurs when the greatest working tooth depth is used. Most pumps have gears with either 10 or 12 teeth. As a spur gear rotates, individual "segments" of fluid are released between the teeth to the outlet, pulsing or ripping the output pressure. This ripple can be avoided through use of helical gears, in which the segments of fluid are released more evenly. The helicals offer another advantage, in that more teeth are in contact at one time, and the driving load is transferred gradually and uniformly as successive teeth come into engagement. Helical gears operate more smoothly and can carry larger loads at higher speeds than spur gear pumps. But a helical gear pump carries less fluid than a spur unit of the same size. Also, helical gears tend to develop end thrust in opposite directions on the drive and driven gears.

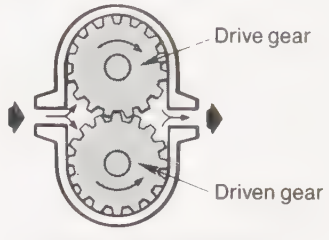
Axial flow (screw) pumps consist of two or more screwlike rotors that mesh in edge contact as they turn. For best sealing, the gears are of considerable length, and the casing fits the gears closely. These gears are capable of high speeds, and produce pressures of 3,000 psi and higher.

Because of their quiet, steady delivery of fluid under pressure, screw pumps are used extensively in hydraulic systems where noise is a major concern. The pumps are also highly tolerant of contamination.

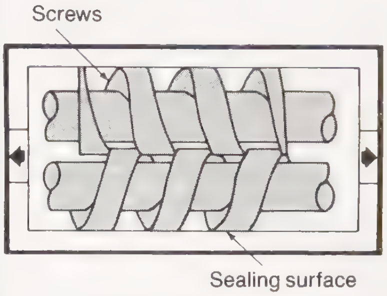
Three-gear pumps, which consist of three gears stacked on top of one another, can work either as dual pumps or as larger single pumps. When used as a single pump, the pressure load on the center gear is balanced. The two outside gears have a pressure imbalance similar to that on a conventional gear pump. The chief advantage of a three-gear pump is that it provides about double the flow of a two-gear unit, without a significantly larger, more expensive package. A limited disadvantage is the relatively short leakage path between pressure and suction sides of the center gear. As a result, these pumps are rarely used in systems that operate at more than 1,200 psi.

Gear-within-gear pumps consist of an externally toothed gear rotating inside and driving a larger internally toothed gear. Several configurations are available. In one, a crescent-shaped separator is required to seal between the two. In another, the inner gear has one tooth less than the outer gear; as the inner gear drives the outer one, the conjugate action of the gear teeth creates sliding seal points. Different names are used to describe gear-within-gear pumps. The most common are crescent gear (for the one with the sealing crescent) and gerotor for the unseparated pump.

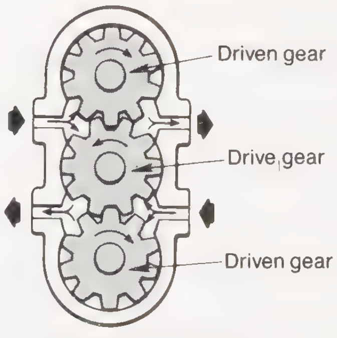
Pumping action of these pumps is the same as that in a spur gear pump. As the teeth unmesh, a vacuum filled by the oil from the inlet port is created. Pockets between the teeth convey the oil to the outlet side where engaging teeth force the oil out the discharge port.



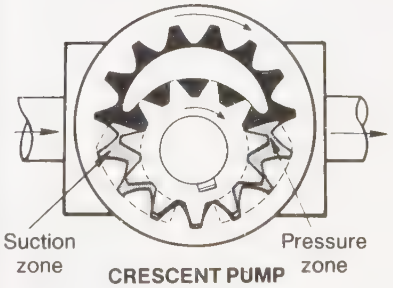
GEAR-ON-GEAR PUMP



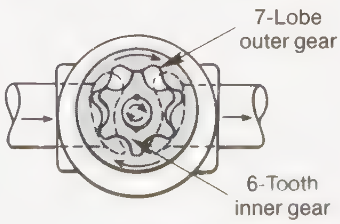
SCREW-GEAR PUMP



THREE-GEAR PUMP



CRESCENT PUMP



GEROTOR PUMP

temperatures and drain periods may be required for optimum performance. Maximum speed and pressure permitted may also be reduced, with pump life cut up to 50% with some fluids.

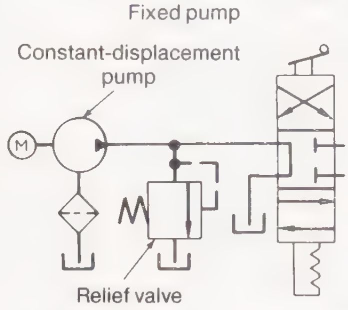
Wear of hydraulic pumps, motors, and valves is relatively low during full-film lubrication, but high during boundary lubrication. The simplest way to guard against excessive wear is to maintain reasonably high viscosity. Some manufacturers recommend that fluids have an adequate concentration of antiwear additives that can protect against wear, even during boundary lubrication.

While no all-encompassing standard for rating hydraulic fluid performance exists today, some component manufacturers and users have developed widely recognized specifications for fluids. The guidelines evolved to meet the needs of the particular manufacturer, and overcome deficiencies each saw when certain fluids were used in their equipment. Most premium hydraulic fluids used today meet the requirements of these rating systems. The design engineer, in general, should not be concerned with the exact nature of the tests, but merely that the fluid meets the recommendations for a particular type of pump and application.

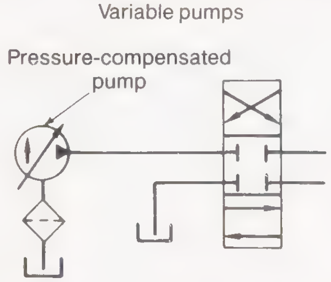
Test data on "typical" pumps is readily available from most fluid suppliers, but there are some instances where field and bench experience do not correlate well. Subtle differences in pump design and conditions of use can drastically change wear rates.

Size and weight: Straightforward comparison of size and weight characteristics by basic pump type is prevented by the overlap of individual designs. For instance, the axial-piston design that is widely used in industrial, marine, and aircraft applications can have many power/weight ratios, depending on the applications for which it is built. One common type of mobile

FIXED VS. VARIABLE PUMPS



In fixed-displacement pump systems, maximum pump discharge pressure depends on the load resistance encountered by the actuator. Flow rate from the pump is constant at constant pump speed. Actuators are sized to meet maximum velocity requirements and, because flow is constant, actuator speed is controlled by throttling.



In variable-displacement pump systems, maximum system pressure depends on the deadhead setting of the pump pressure-compensator control. Flow is a function of overall system dynamics and matches the instantaneous needs of the actuator. Actuators are sized to meet the load requirements, and actuator speed is controlled by throttling flow.

VANE PUMPS

A typical vane pump consists of a circular rotor mounted eccentrically in a circular cavity. As the rotor spins, vanes in the pump extend and retract to seal against the cavity surface, sometimes called a cam ring. Fluid is trapped between the vanes at the inlet, swept along by the vanes, and propelled through the outlet.

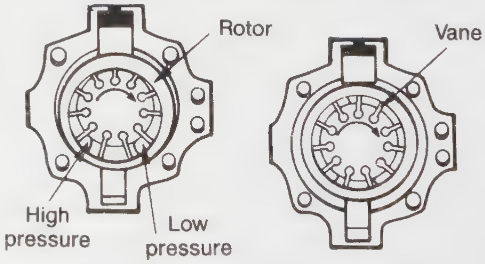
Vane pumps are efficient, and usually provide enough extra vane length to accommodate wear. They are less sensitive to contaminants than piston pumps, but more sensitive than gear pumps. On the other hand, they usually require a fairly high start-up speed — usually about 600 rpm to bring vane tips into contact with the cam ring; below this speed, leakage is high and efficiency is low. If the vanes are worn so severely that a vane slips out of the rotor or becomes "cocked" during operation, failure is prompt and disastrous. And the basic pump is subjected to high bearing loads because it is unbalanced — it has a high-pressure area on one side of the rotor and a low-pressure area on the other that tends to force the rotor and shaft down against the bearings.

The answer to the latter problem is the so-called balanced vane pump. In this, an elliptical cam ring with the rotor centered produces two chambers, or "annuli," at each end of the pump. Four ports are required to get the fluid in and out. With this configuration, two diametrically opposed high-pressure zones balance out forces on the pump shaft.

Variable-displacement vane pumps allow great controllability of output flow, usually variable between zero and maximum. At low pressure, a special governor spring loads the cam ring toward the rotor, so that the pump delivers full-rated flow at full displacement. As pressure in the pump increases, the fluid forces the cam ring back against the spring, tending to center the cam ring around the rotor. At maximum, or preset, pressure, the rotor is neatly centered, and output flow is zero. Other pumps can be made to deliver variable displacement in various ways, but only with the vane pump is variable displacement so easily obtained.

Other variable-displacement vane pumps are built so the ring is shifted by a manual control lever, or by an electric, hydraulic, or pneumatic actuator. Still other pumps are constructed so that the eccentricity is rotated to vary the displacement.

The main advantage of a variable-displacement pump is low-power consumption. Only enough power is extracted from the drive to do the required job. Because the cam ring must be shifted to vary output, variable-volume vane pumps cannot have the close tolerances of fixed-displacement pumps. This is particularly true of pressure-compensated types, where the ring must be relatively free. Efficiencies of these pumps are not as high as those for fixed-displacement types. Some newer types of variable-volume pumps use pressure-loaded side plates to cut leakage and boost efficiency.



VARIABLE-VOLUME VANE PUMP

Compound pumps are vane units with two or more rotors mounted on a common shaft within a common housing. These are sometimes called "tandem" or "double" pumps. Each section has its own inlet and outlet ports and can power an independent circuit. Another form of compound pump consists of two separate pumps mounted on the same shaft, with the two sections in hydraulic series. Output from the first section enters the inlet of the second. Pressure is boosted the same amount in each stage, so the total pressure boost is twice that of a single stage.

PISTON PUMPS

Piston pumps offer the highest performance — at a price. The pumps used in aerospace and aircraft are typically bent-axis piston pumps, tiny units built with jewellike precision to deliver extremely high flows at very high rotating speeds. Some of the smallest are rated at rotating speeds to 25,000 rpm, with displacements as low as 0.003 in.^{3}/rev. In industry, however, swashplate piston pumps are often directly competitive in terms of capabilities with high-pressure vane and gear pumps. These pumps are extremely efficient, with volumetric efficiencies as high as 99%. And the industrial piston pumps are relatively less expensive than they were years ago.

Axial piston pumps convert rotary motion of an input shaft to an axial, reciprocating motion of one or more pistons. This is usually done by use of an angled cam or wobble plate. As the wobble plate rotates, the pistons reciprocate, taking fluid while moving toward the thin part of the plate and expelling it while approaching the thick end. An alternative way to reciprocate the pistons is through a bent driving axis, where both the pistons and shaft rotate. For this design, no wobble plate is required because of the angled relationship of the pistons and shafts. In some pumps, flow in and out of the pistons is regulated with a flat valve plate with two kidney-shaped ports; other pumps use a series of individual check valves for the various pistons. Each approach is suitable for normal use, but the method used is typically claimed as a proprietary advantage by both valve-plate proponents and check-valve backers.

Check-valve piston pumps are said to be rugged, tolerating cavitation and shock. These pumps can rotate in either direction, and can operate at reduced effectiveness after valves for any one piston fail. The pump can also have two or more individually controlled and regulated outputs, much like a tandem vane pump.

Valve plate piston pumps, on the other hand, offer the advantages of simplicity, ease of maintenance, and flow reversibility. Most of the valve-plate pumps permit variable delivery to be designed into the pump as one of its features. Displacement in these pumps is varied by changing the axis angle, or the angle of the swashplate. Most check-valve pumps have no way to vary displacement; rather, delivery is varied by bypassing part of the pump fluid back to the tank or inlet line through a bypass valve.

Infinite variations on these two themes are available. In some pumps, the piston and barrel rotate together against a stationary swashplate. In others, the plates wobbles against pistons that do not rotate. The end result of design variations is typically noted in the cost of the pump, rather than in its performance characteristics. Although performance may be affected by these incremental changes, the amount of change is usually not enough to displace these units from their basic position in the piston pump category.

Radial piston pumps convert rotary shaft motion into a radial reciprocating motion of the pistons. As with axial piston types, radial-piston pumps come in both fixed and variable-delivery configurations.

Check-valve radial-piston pumps are usually driven by a rotating cam that runs through the center of the pump. The cam reciprocates the pistons. Fluid flow into and out of the pistons is controlled by check valves. Delivery is varied by bypassing part of the flow, or by hydrostatically holding the pistons away from the cam to vary the stroke.

Pintle-valve pumps have radial pistons and a rotating cylinder block, with the heads of the pistons engaging an eccentrically mounted stationary reaction ring. Centrifugal force and back pressure hold the pistons in contact with the ring during suction or (in alternative designs) notched piston tips may ride in grooves on the ring. As the cylinder block rotates, the pistons are reciprocated as they rotate around the surface of the eccentric ring. The piston cavities fill with fluid from the inlet side of the stationary pintle; as the piston moves to the top half of the pump, it begins to stroke outward, emptying fluid into the outlet side of the pintle.

Delivery of this type of pump is varied by moving the reaction ring relative to the cylinder block, thus increasing or decreasing eccentricity. If the ring is moved to the left so that eccentricity is decreased, length of piston stroke is also diminished, as is the amount of fluid pumped. In some models, the ring can be moved over center, so that flow reverses. The outlet side of the pintle becomes the inlet, and vice versa.

pump has a ratio around 0.75 hp/lb; others may be 2.5 hp/lb. The additional expense of a highly refined piston pump capable of delivering 4 hp/lb is warranted for aircraft use, where every pound carries a double penalty. When reduced to miniature size for missile use (and when life is sacrificed for power), the same basic mechanism may deliver 8 hp/lb.

Environment: Usually, effect of ambient temperature and altitude on performance is independent of the type of pump. Limits for satisfactory operation are established primarily by the effect of the environment on the fluid rather than by the type of pumping action. Humidity only affects requirements for the exterior casing.

When minimum or maximum temperatures are specified for a hydraulic system, the operating temperature of the fluid, not ambient temperature, is the critical factor. In most cases, it is possible to compensate for extremes of ambient temperature and to control fluid temperatures within a satisfactory range.

Minimum operating temperature is generally set by the increase in fluid viscosity as temperature falls. When fluid thickens to the point where inlet conditions can no longer keep the pump completely full, cavitation — with possible pump damage — occurs. Fire-resistant fluids have a higher specific gravity than petroleum oils, accompanied in some cases by higher viscosities at low temperatures. Many fire-resistant fluids contain water, which can vaporize if pressures are low or temperatures high. Thus, pump-inlet conditions are more sensitive when these fluids are used. High altitudes can produce a somewhat similar effect when the fluid reservoir is not pressurized. The usual solution is to supercharge the main pump with an auxiliary pump, or to flood the inlet by locating it below the fluid level in the reservoir.

Maximum allowable operating temperature depends on the properties of the fluid seals being used. Above allowable temperatures, many oils will be too thin to maintain proper lubrication at high-load points, and may progressively deteriorate as a result of oxidation. Under elevated temperatures, some seals may harden.

Pump controls

To minimize wasted energy in hydraulic systems, variable-displacement pumps were developed. They reduce power loss by adjusting the relationship between pressure and flow for various power levels. Electrohydraulic control of flow and pressure directly at the pump often permits more flexibility and more efficient operation of variable-volume pumps, and reduces the number of valves in a circuit.

The basics of electronic pump control are rather straightforward. A programmable controller, PC, microprocessor, potentiometer, or other such device provides a signal to an electronic driver board, or amplifier card. This low-current signal is amplified into either a pulse-width-modulated signal sufficient to drive proportional solenoids on the pump, or an amplified current signal to drive proportional pressure controllers (PPC).

The solenoids or PPC convert current to a proportional force, providing pressure control to a piston which adjusts the ring position in a variable vane pump, or the swash plate in an axial piston pump, in turn controlling pressure and flow.

Repeatability when moving from low to intermediate pressure is typically within 1%. Linearity is generally within 3% for flow, and 4% for pressure control. Due to hysteresis when cycling up and down, pressure differential can be as much as 4%. Usually, this is not a problem, because the input signal can be adjusted to compensate for the difference. However, when precise linearity is a must, closed-loop feedback is necessary.

With closed-loop control, command inputs, amplifier card, and pump hardware remain the same. Sensors are added to the system to measure the desired parameter, along with an electronic summing card that compares input with actual output. If pressure must be controlled precisely, a pressure transducer is added to the system. For flow control, an LVDT can be connected to the cam ring or swash plate to monitor position and, thus, flow. If the pump is driving a hydraulic motor, a tachometer can be used to sense motor speed and adjust pump flow as necessary.

The benefits to using electrohydraulic control are numerous. A major factor is the tremendous energy savings — 40 to 50% is not uncommon — realized by applying these controls. Accuracy is enhanced, especially with closed-loop feedback control.

A circuit can be substantially simplified by moving to electronic pump control, because valving is eliminated. For a complicated circuit, the cost of pressure and flow control valves, manifolds, connectors and other plumbing, often exceeds that of the controller and other electronics. Because the circuit is generally simplified, and control and power elements are separate entities, tracking down a problem area is usually simplified. By disconnecting the electronics and actuating the pump manually, one quickly determines if the problem is a hydraulic one. If not, the problem probably lies in the electronics. The error can then be isolated by checking inputs and outputs at the controller and boards.

Programming these controls is not

MECHANICAL CONTROL

A number of hydromechanical controls have been developed over the years to modulate pump flow and pressure. Compared to electronic control, these controls do have certain limitations. System performance, while good, is less than optimum. The controls do not allow a great deal of flexibility. Controlling from a remote location is usually not practical. And some control features are simply impractical or impossible without electronics. However, in many cases these still represent the most cost-effective and reliable approach to pump control.

To minimize wasted energy in hydraulic systems, variable-displacement pumps were developed. They reduce power loss by adjusting the relationship between pressure and flow for the various power levels.

Many controls have been developed that tailor the pressure/flow relationship to meet a variety of needs. Most controls are based on a pressure compensator, which is then modified to enhance or limit certain operating characteristics of the pump.

Pressure compensation: An older technique for conserving energy is to maintain system pressure at zero flow through the use of a pressure-compensated pump. A pressure compensator is simply a force-balanced mechanism that senses system pressure and destrokes the pump at a preset cutoff pressure. Therefore, all pressure-compensated pumps must also be variable-displacement pumps.

At maximum efficiency, pressure-compensated pumps must be used in closed-center valve systems. The advantage of such a system becomes clear in applications where the duty cycle includes periods of low flow at relatively high pressure. In this mode, losses in an open-center system greatly exceed those from a closed-center system.

Load sensing: The power loss penalty of a closed-center system can be avoided by using a load-sensing variable-pump system. In this system, the pressure compensator controls the displacement of the variable pump and senses both pump outlet pressure and load pressure. The compensator varies pump stroke to maintain a constant differential between the pressures; that is a constant differential across the load valve.

Another feature of a load-sensing control is that a given valve position produces essentially constant load velocity because pressure drop across the valve is independent of load. This contrasts with the operation of simple pressure-compensated systems, in which load velocity decreases as the load increases for a given valve setting.

Torque limiting: Applications such as lift trucks, loaders, and cranes require a wide load range. Reduced speed at heavier loads is acceptable or even preferable. In such situations, a variable pump with a torque-limiting control may provide the most effective operation. Such a control permits a smaller prime mover to be selected, but maintains full-load velocity at moderate loads and preserves the ability to move heavy loads when necessary.

With a torque-limiting control, when load pressure is low, the flow limit is high, providing high load velocity and high machine productivity. As load pressure increases, the pump stroke control automatically decreases the flow limit to maintain nearly constant pump driving torque. Thus, the load is moved at reduced speed without exceeding the torque capability of the prime mover.

The maximum pressure available is usually set by a pressure-limiting control, so that pump flow drops to zero if the load is stalled. In addition, pumps with torque limiting and pressure limiting may also have load-sensing controls to minimize power loss when a moderate load must be moved at relatively low speed.

Torque summation: In some applications, hydraulic power is generated by two or more large pumps driven by the same prime mover. This is done by driving a pump from both ends of an electric motor or by mounting multiple pumps on a splitter gearbox driven by an engine, as on an excavator. To provide maximum productivity and avoid stalling the prime mover, the torque of both pumps must be summed so that total torque falls within prime-mover limits. Either the pump stroke mechanisms must be coupled together and operated by a single control, or each pump must sense not only its own torque but that of its neighbor.

The first method produces identical flow from each pump, regardless of the flow required by the operator. The second method is more flexible, allowing pump flows to vary according to operator demand while still maintaining an overall torque limit. The second method of torque summation can also be used to sum the torque of a fixed and a variable unit, with the stroke of the variable pump modulated to maintain an overall torque limit.

Speed sensing: In applications such as vehicles with mechanical traction drives, a large amount of prime-mover power is delivered through some form of mechanical transmission for certain operating modes. For other modes, a large amount of hydraulic power may be generated. Where the prime mover cannot satisfy both types of peak demands simultaneously, hydraulic power may have to be limited during periods of high transmission-power demands.

Because there is no convenient way to obtain a signal from a mechanical transmission that is proportional to its torque level, some other measure of prime-mover torque output must be used. A signal that is proportional to prime-mover speed may be provided. As the torque limit is approached, speed normally drops sufficiently so that the signal change can be used to unload the pump, preventing prime-mover stall.

Wide-differential compensator: A wide-differential compensator is best when two or more pumps are operated in parallel, and the load must be shared evenly. It has some of the characteristics of a torque-limiting control in that it gives relatively high flow at a moderate pressure. A still higher peak-pressure capability to move a heavy load at reduced speed is also available.

When used with a fixed pump, a wide-differential compensator provides a close approximation to a torque-limiting control. A fixed-pump, open-center valve system can be given an output boost at low load pressures by this means without exceeding the power limits of the prime mover.

Displacement control: Sometimes the operator must control pump displacement directly. This may be done through a manual device lever or handwheel or through a servo to reduce operator force levels and permit remote control. Displacement controls typically are used in winches, swing drives, or velocity controls. To permit reverse operation, most variable pumps with displacement controls are designed to go "overcenter" and pump in either direction.

Displacement controls normally are used when the pump drives a single load. A displacement control is inherently load sensitive, providing only the pressure and flow needed to move the load; therefore, it is highly energy efficient. To prevent shock loads from abrupt control motions by the operator, many pumps with displacement controls have some form of pressure-limiting override to limit or moderate pump stroke changes.

Torque select: In this design, the operator chooses the required pump output pressure, thus establishing the hydraulic motor torque and the load-acceleration rate. The pump increases displacement smoothly to accelerate the load at a uniform rate determined by the pressure. When the required load velocity is reached, the operator returns the control to neutral, or to a lower pressure setting, to maintain constant load velocity. The load is slowed regeneratively to a stop by reversing the control. The rate of deceleration is again determined by the pressure setting selected by the operator. This type of control prevents both shock loads and discharge over a relief valve with resulting heat generation, while still allowing maximum acceleration rates.

very complicated, because pump outputs are directly proportional to command inputs. Programmable controllers are used most often, so programming is really just a matter of setting voltage or current, and timing. Loading a new program to the controller is all that is necessary to change operation, resulting in more flexibility and substantial setup time savings.

Because of precise control over acceleration and deceleration, cycles times can be decreased without introducing detrimental impact loads. Because the pump always operates at the lowest possible pressure, pump life can be extended dramatically, and these controls are, for the most part, adapted for retrofit onto standard pumps in the field today.

One possible drawback to electrohydraulic pump control is that there is only one pressure or flow to work with at one time. For applications that require two or more simultaneous pressure or flows, some sort of valving must be used.

This method cannot be used to control stationary position of an actuator. Acceleration to a general location is performed well by electrohydraulic pumps, but stopping a specific position requires valves.

Because the pump is controlled by pressure compensation, it will not work if system pressure falls below the pump's minimum deadhead value. If control is needed at low load pressures, either an artificial load pressure must be generated at the pump outlet, or another means of control must be used. Also, controls affect only swash plate or ring position, and do not compensate for pump inefficiency or fluid compression. Closed-loop feedback is needed should such compensation be necessary.

Power units

Sometimes the complexity and magnitude of a job suggest that a system of separate hydraulic components would be difficult to put into action. In such a case, a power unit consisting of a reservoir, pump, drive motor, filter, heat exchanger, and basic system valving could be used. The pump includes integral controls, perhaps an auxiliary supercharge pump, and relief valves. The reservoir includes inlet filter, all necessary line connections, fluid level and temperature gages, lifting lugs, and observation and clean-out covers. This type of power unit is a fine example of operational convenience.

Manufacturers agree that an assembled unit is more expensive than a combination of components purchased separately. But they suggest that the additional cost is offset by the fact that the user need not select the components, design the system, build it, or troubleshoot it. They point out that hydraulic power units with compatible components, supplied by one manufacturer for a specific system, usually provide maximum system efficiency, controllability, and durability, with minimum noise.

The heart of a system is one or more pumps. For simple push-pull applications or constant power drive, a fixed delivery, one-way pump may be adequate. In applications requiring more complex functions, a variable-displacement unit is probably necessary. In either case, the system should have adequate reserve capacity.

Although most pump controls merely select the output volume or flow, other functions can be provided. These include controls of generative and regenerative direction of flow, acceleration, and deceleration of flow, zero flow, limiting pressures, constant power, automatic decompression, and automatic interlocks.

Many control modes are possible: Mechanical, hydraulic, pneumatic, electric, and electrohydraulic controls are available. The simplest direct control is a hand-operated screw. Mechanical extensions or electric pilot motors with geared head, brakes, and limit switches provide remote operation. Low-pressure hydraulic control circuits or low-power electrical circuits permit remote selection of multiple volumes. And hydraulic servomotor controls can be used to provide automatic control of high accuracy.

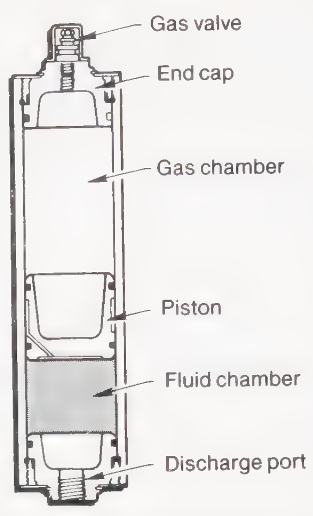
Any type of drive can be supplied with a power unit: electric motor, diesel engine, gas turbine, line shaft, or others. The most widely used drive is an electric motor directly coupled to the pump through a flexible coupling.

To design and build a power unit, the project engineer must know, among other things: 1. Type of machine or application. 2. Work to be performed. 3. Maximum force and working pressure required. 4. Minimum and maximum working speeds. 5. Size and weight of machine moving parts. 6. Type and accuracy of control and functions. 7. Type of service cycle. 8. Type of input power available to power unit. 9. Space available. 10. Heat-exchange method required. 11. Noise specifications. 12. Any unusual conditions of the application, special requirements, or environmental conditions.

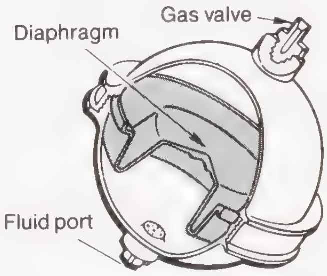
Accumulators

Because of their ability to store excess energy and release it when needed, accumulators are useful tools in developing efficient hydraulic systems. Selecting an accumulator involves two tasks. First, the correct type of accumulator must be determined. Then, capacity, precharge, and size are chosen.

Separated gas-loaded accumulators are the most common types. They are self-contained, small, and light. Depending on the type, their response is rapid, and they are somewhat inexpensive and easy to maintain.



PISTON ACCUMULATOR



DIAPHRAGM ACCUMULATOR

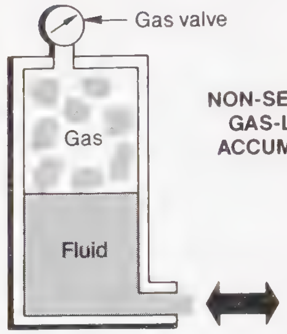
The separator, which keeps gas from liquid, may be a piston, bag, or diaphragm. In the piston type, the accumulator is basically a cylinder with high-pressure gas on one side, fluid on the other, and a free-floating piston in between.

A diaphragm unit, as the name implies, contains a diaphragm separating gas and liquid. Diaphragm units are frequently spherical, producing high fluid volumes in a minimum weight and exterior size.

Bag accumulators have a cylindrical shell with a rubber bladder inside. Gas is enclosed in the bladder, and hydraulic fluid fills the space around it.

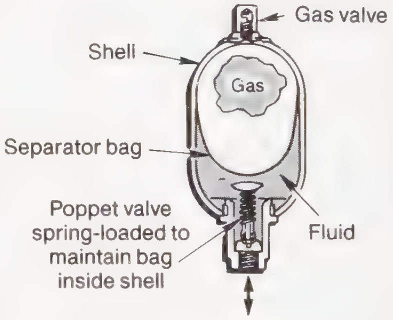
Nonseparated gas-loaded accumulators consist of a tank partially preloaded with a gas. The gas is trapped above the liquid; level switches prevent the trapped gas from escaping out of the fluid port if the liquid level becomes too low.

This type of accumulator responds more rapidly than either weight or spring-loaded units, and permits the storage of extremely large volumes of fluid. However, the fluid tends to become aerated because of the air acting directly on the fluid; in addition, the combination of accumulator, special controls, valves, and the compressor that is possibly needed for preload makes for a complicated system.



NON-SEPARATED GAS-LOADED ACCUMULATOR

Spring-loaded accumulators consist of a spring-loaded piston in a cylinder. Energy is stored as the spring is compressed by fluid flowing into the accumulator. This type of system offers faster response than weight-loaded accumulators, but shares the large size and cost. Maintenance cost, however, is quite low. Accumulator pressure varies with spring compression.



BLADDER ACCUMULATOR

Weight-loaded accumulators consist of a long vertical piston mounted within a honed or ground cylinder. The piston is weighted to create the pressure in the cylinder chamber. Fluid level in the chamber is maintained by a system of limit switches that controls the pump and motor. This type of accumulator provides constant pressure, regardless of fluid level; however, it is large and heavy, and slow to respond to quick demands because of inertia.

Intensifiers

Intensifiers, also known as boosters, use a large quantity of low-pressure fluid to produce a smaller quantity of higher-pressure fluid. There are three classes of intensifiers: air-to-oil, oil-to-oil, and air-to-air.

Hydraulic boosters can develop and maintain high pressure for long periods of time without using power or generating heat in the circuit. They deliver fluid only when the cylinder demands it. Since all the oil from the booster is directed to the cylinder, there are no relief-valve losses.

Other advantages exist:

- Because heat is not generated while static hydraulic pressure is maintained and little is generated during rapid cycling, small oil reserves are required.
- Direction control of booster-operated cylinders is through air valves which are usually less expensive than hydraulic valves, but just as reliable. Pressure regulation of booster discharge is controlled by an economical air pressure-regulator valve.
- Because high hydraulic pressure is easily attained, booster-operated cylinders can be smaller in diameter. Booster systems are generally more compact than equivalent pump-and-tank units.
- Because pressure and direction-control valves are located in the air portion of the air-oil booster circuits, few fittings and usually no valves are required in the booster-to-cylinder connection.
- Air-to-air boosters permit the use of low-cost air cylinders at line pressures greater than those available from normal shop-air compressors.

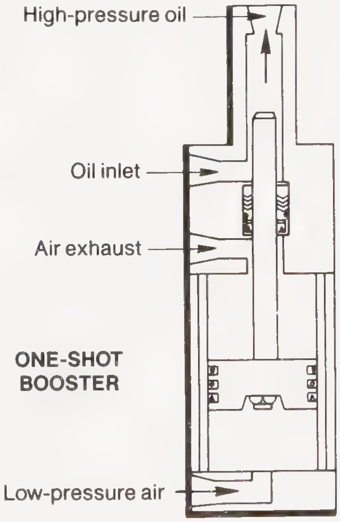
Generally, boosters can be used as a hydraulic power source only in single-cylinder applications. A booster can drive more than one cylinder if the cylinders work in unison. However, to sequence two or more cylinders, additional boosters are required.

Boosters are limited in their volumetric capacity. For large quantities of high-pressure air or oil, large boosters are required. The double-pressure booster circuit can be used, but only if the driven cylinder load can be divided into a low-pressure traverse stroke and a reasonably short high-pressure stroke. If the high-pressure stroke must be long, and if the cycle must repeat rapidly, single-ram boosters offer little advantage.

Single-ram boosters are limited in their capacity to supply high-pressure oil. Therefore, only certain types of hydraulic valves can be used in air-to-oil booster circuits. Valves that have tank drainbacks should be avoided, because they use booster capacity during operation. Four-way hydraulic valves should also be avoided, because they generally cause momentary pressure drops in the system and throw the booster out of phase with the cylinder.

Because air is compressible, air-to-air boosters are somewhat less predictable than other types. However, if a stroke/diameter ratio of 3.7:1 is used to determine size of the output cylinder, calculated volumetric ratios of slave cylinder vs. output cylinder should produce accurate results.

Selection of a booster type is probably the easiest decision of all. If a ready supply of shop air is available, an air-to-oil booster will be used. If low-pressure hydraulic fluid is readily available, an oil-to-oil booster is the best choice. If a one-shot source of fluid for clamping and holding is required, a normal one-shot booster will be used. However, if a continuous supply of fluid is required to reciprocate a cylinder or rotate a motor, a continuous booster should be considered.



Continuous boosters replace a pump in the system because they provide a steady output of high-pressure fluid. The two types are double acting and single acting. Both require valving or external controls to produce the necessary reciprocating action, but the single-acting model is generally simpler. Double-acting continuous boosters supply oil during both parts of the stroke. Therefore, output generally has less ripple.

IMPROVING SYSTEM PERFORMANCE

An accumulator is a simple mechanical device that stores the energy of fluid under pressure. The stored energy is readily available as a quick secondary source of fluid power. The following are ways in which this energy can be used productively:

Auxiliary power can be produced by an accumulator in intermittent-duty systems. The accumulator is used as a secondary power source with a small pumping unit acting as the primary source. The pump is used to charge the accumulator, which supplies the high flow demand of the cylinder.

Cavitation of piston pumps can be prevented by installing an accumulator close to the pump inlet. The accumulator pressurizes the inlet, reduces the effective length of the inlet line, and absorbs excess kinetic energy. The first two functions combine to reduce or eliminate cavitation, while the third combats wear-inducing vibration.

Dual-pressure circuits permit fast motion at low pressure during the early part of a stroke, plus slow motion at high pressure at the end of the stroke. During the "hold" portion of the cycle, pressure on the ram is supplied by the high-pressure pump, and the accumulator is recharged by the low-pressure pump. When rapid extension is required, fluid is expelled from the accumulator to extend the actuator.

Emergency power can also be provided by an accumulator. If the hydraulic system fails upstream of the check valves, the accumulator operates the system to hold the actuators in position.

Increasing flow capacity of a power unit increases machine productivity, thereby boosting energy efficiency. Flow can be increased by using a large pump, but this can be costly. A more cost-effective approach is to add an accumulator between the pump and directional-control valve. In operation, the pump charges the accumulator during the dwell time, and the accumulator augments pump flow to cycle the actuator.

Makeup fluid can be supplied by an accumulator where pressure must be held for long periods of time. The accumulator makes up leakage that can occur over long periods, while the system pump supplies fluid to other parts of the circuit. A closed-center valve isolates the accumulator and cylinder.

Three major steps are involved in selecting the right booster for an application. First, booster size must be determined, making provisions for fluid compressibility. Next, the size of the makeup fluid tank must be determined, allowing for bleeding air from the fluid. Finally, output speed of the actuator must be checked to ensure that it is sufficient for the selected booster.

Booster size: If a cylinder requires high-pressure delivery throughout the stroke, a single-pressure booster circuit is needed. A double-headed booster can be used if the number of cycles per minute is low, and automatic bleeding and filling are not important. A triple-headed type must be used where rapid cycling is required. If the cylinder size is known, stroke, L, for a single-pressure booster can be calculated from

$$L = \frac{V_c V_o}{A_r} + l$$

Where V_c = total cylinder volume, V_o = oil volume loss due to compressibility, A_r = booster ram area, and l = booster ram pretravel.

If the maximum cylinder force is required only for the last portion of the stroke, a double-pressure booster can be used, with savings in booster size and air consumption. With such a booster, the normal circuit extends the actuator, and the booster supplies fluid only for the maximum force portion of the stroke. Booster stroke L for this arrangement is:

$$L = \frac{V_P + V_o}{A_r} + l$$

Where Vp = volume required to move the cylinder through the high-pressure portion of the stroke.

Both equations contain a term for oil compressibility. In most hydraulic applications, oil is considered incompressible. But in high-pressure applications, it is safer to assume that oil can be compressed at the rate of approximately 1% per 1,000 psi.

Tank size: The air-oil tanks in booster circuits perform three general functions: 1. Make up for leakage. 2. Act as pressure sources to traverse or return cylinder. 3. Provide outlets for entrained air.

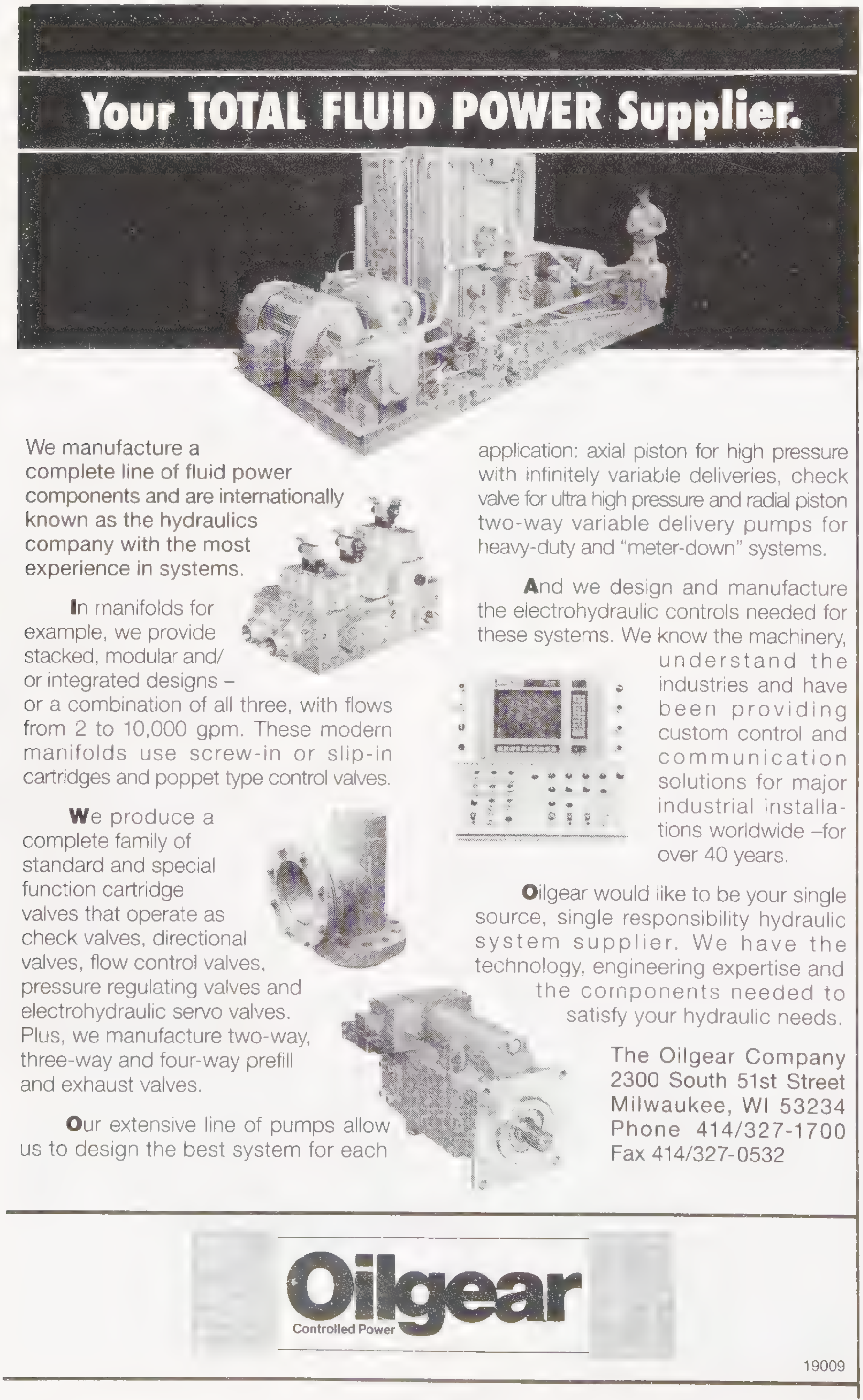
When the tank functions as a reservoir, its size depends on how much the system leaks. However, tanks are also outlets for entrained air. Here, the tank is not pressurized and acts primarily as a reservoir.

When functioning as a pressure source, tanks must have a volume slightly greater than the displaced volume of the cylinder. Volume of the tank should be enough to preclude oil level reaching the upper tank baffle at the high-level point. When at the low-level point, the lower tank baffle should not be exposed to air pressure. Pressurized tanks must also serve as an outlet for entrained air.

In rapid-cycle booster applications, oil has a tendency to churn as it flows back into the tank. This churning aerates the oil and produces excessive foaming. Each cycle then sprays foam out the air-valve exhaust. Well-designed tank baffles eliminate churning at oil velocities below 15 fps. A tank larger in diameter than the cylinder results in better surface quiescence during the fill stroke.

Tanks for rapid-cycle booster applications should have:

- Ports equal to or larger than the cylinder ports. Cycle rate should be set so that the flow through the interconnecting pipes does not exceed 15 fps.


Your TOTAL FLUID POWER Supplier.

We manufacture a complete line of fluid power components and are internationally known as the hydraulics company with the most experience in systems.

In manifolds for example, we provide stacked, modular and/or integrated designs – or a combination of all three, with flows from 2 to 10,000 gpm. These modern manifolds use screw-in or slip-in cartridges and poppet type control valves.

We produce a complete family of standard and special function cartridge valves that operate as check valves, directional valves, flow control valves, pressure regulating valves and electrohydraulic servo valves. Plus, we manufacture two-way, three-way and four-way prefill and exhaust valves.

Our extensive line of pumps allow us to design the best system for each application: axial piston for high pressure with infinitely variable deliveries, check valve for ultra high pressure and radial piston two-way variable delivery pumps for heavy-duty and "meter-down" systems.

And we design and manufacture the electrohydraulic controls needed for these systems. We know the machinery, understand the industries and have been providing custom control and communication solutions for major industrial installations worldwide –for over 40 years.

Oilgear would like to be your single source, single responsibility hydraulic system supplier. We have the technology, engineering expertise and the components needed to satisfy your hydraulic needs.

The Oilgear Company
2300 South 51st Street
Milwaukee, WI 53234
Phone 414/327-1700
Fax 414/327-0532

Oilgear
Controlled Power

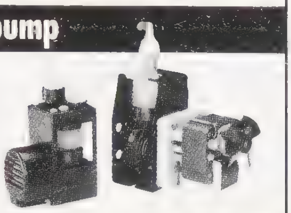
19009

Circle 490

FULL LINE OF OEM FLUID HANDLING PUMPS

Bellows metering pump
Corrosion and chemical resistant. Single or tandem models. Accurate to +/- .5%. Self-priming. No seals. Can run dry. Flows from 1.9 ml/min to 5200 ml/min.

Compact & mini bellows pump
Self-priming metering pumps, accurate to +/- .75%. Flow rates to 324 ml/min (mini) and 945 ml/min (compact). Discharge pressures to 5 psi. Economical. Tandem models available.

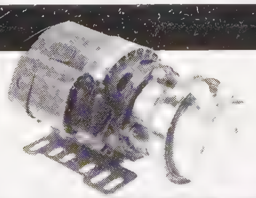


Oscillating pump
Self-priming to 48 inches. Corrosion-resistant. No seals. Flows to 1.2 gpm with discharge heads to 8.3 feet. FDA accepted materials. Economical.

Magnetic drive pump
Dry run capability, corrosion resistant. Flows to 35 gpm. Discharge heads to 53 feet. Hydraulically efficient.

Centrifugal pump
Flows to 60 gpm and discharge heads to 84 feet. Pumps handle everything from corrosive chemicals to small solids. Efficient and economical.

Nutating pump
High-pressure, corrosion resistant, plastic molded construction. Flows to 4.2 gpm. Self-priming. Self-adjusting pressure limit. No valves or moving seals.



Peristaltic pump
Low cost pumps for handling corrosive solutions. Self-priming to 20', no seals. Flows from 7 to 350 ml/min. Thermally protected gear motors standard.

GORMAN-RUPP™ INDUSTRIES
DIVISION OF THE GORMAN-RUPP COMPANY
Telephone (419) 886-3001 • Fax (419) 886-2338

High quality. Dependable service. Competitively priced.

Circle 491

GUARANTEED PERFORMANCE

GRAHAM-WHITE™ AIR SYSTEMS

"No Refrigerant Required"

DRY The compressed air will be at a predetermined pressure dew point that insures zero liquid water condensation.

OIL FREE Compressed air; liquid oil and oil aerosol levels are reduced by 99.9% +.

CLEAN Abrasive particles in compressed air are removed down to 0.3 microns.

For Further Information
Write, Phone, or FAX
GRAHAM-WHITE MANUFACTURING CO.
P.O. Box 1099 / Dept. G / Salem, VA 24153-1099
(703) 387-5600 / FAX (703) 387-5639

GRAHAM-WHITE MANUFACTURING CO.

CATALOG
NO. D-5000

Ask About Our Special Leasing Program

Circle 492

Flojet Pumps & Motors

Specializing in OEM Requirements

Flojet recognizes the uniqueness of each customer's application and welcomes the opportunity to provide technical assistance. For pump selection and new 32 page catalog - just call (714) 859-4945

- Electric or Air Driven
- Diaphragm & Gear Pump Designs
- Self-Priming & Dry Running
- Chemically Resistant
- Permanent Magnet Motors

FLOJET CORPORATION
12 Morgan • Irvine, CA 92718-2003
(714) 859-4945 • TELEX: 6831943
FAX: (714) 859-1153

Circle 493

- A diameter larger than the cylinder diameter. Tank height should be specified by matching rated-tank capacity with the cylinder displacement.
- Properly designed baffles.
- A location above cylinders and boosters so the system can be self-bleeding.
- A fill rate less than 4 fps.

Experts recommend that self-bleeding boosters be used wherever possible. This type of operation ensures that air does not build up in the system, causing "spongy" operation that impairs function and efficiency.

Air gets into the system in many ways, the most common being the use of two-position air valves. This results in high-pressure air being left "on" for long periods; the air dissolves quickly into the oil, causing spongy operation. This problem can be avoided by using a three-position, open-center valve and arranging the circuit so the tank can be exhausted by centering the valve, yet holding the booster "on." Another alternative is to use a bladder or piston separator in the air-oil tank.

In addition, air exists naturally in most hydraulic fluid, and vacuum in the system — caused when boosters outspeed cylinders on reset — can release air from the fluid. Also, the vacuum can draw air past seals into the system. Air tends to enter the fluid when it churns in the tank. These and other causes can rapidly aerate fluid in even a well-designed system, so the self-bleeding boosters are particularly important for applications that seem prone to aeration.

Cylinder speed: If rapid cylinder action is required, the hydraulic cylinder should be sized so that the reaction force (force required to do work) is 50 to 60% of available cylinder force at calculated pressure. Consider both high-pressure and low-pressure work reactions.

Air valves should be located close to the booster and air-oil tanks, and be connected with a minimum of piping. Three-way and four-way valves should be sized as though they were to operate a rapid-cycle air cylinder directly. The valves should be selected for low-pressure drop, fast response, and adequate internal area.

Air pressure-regulator valves, if used, should be selected for satisfactory flow capacity at regulated pressure, as well as matching port sizes. Self-relieving regulators prevent downstream pressure buildups. An air storage tank between the pressure regulator and the four-way valve optimizes air-valve response.

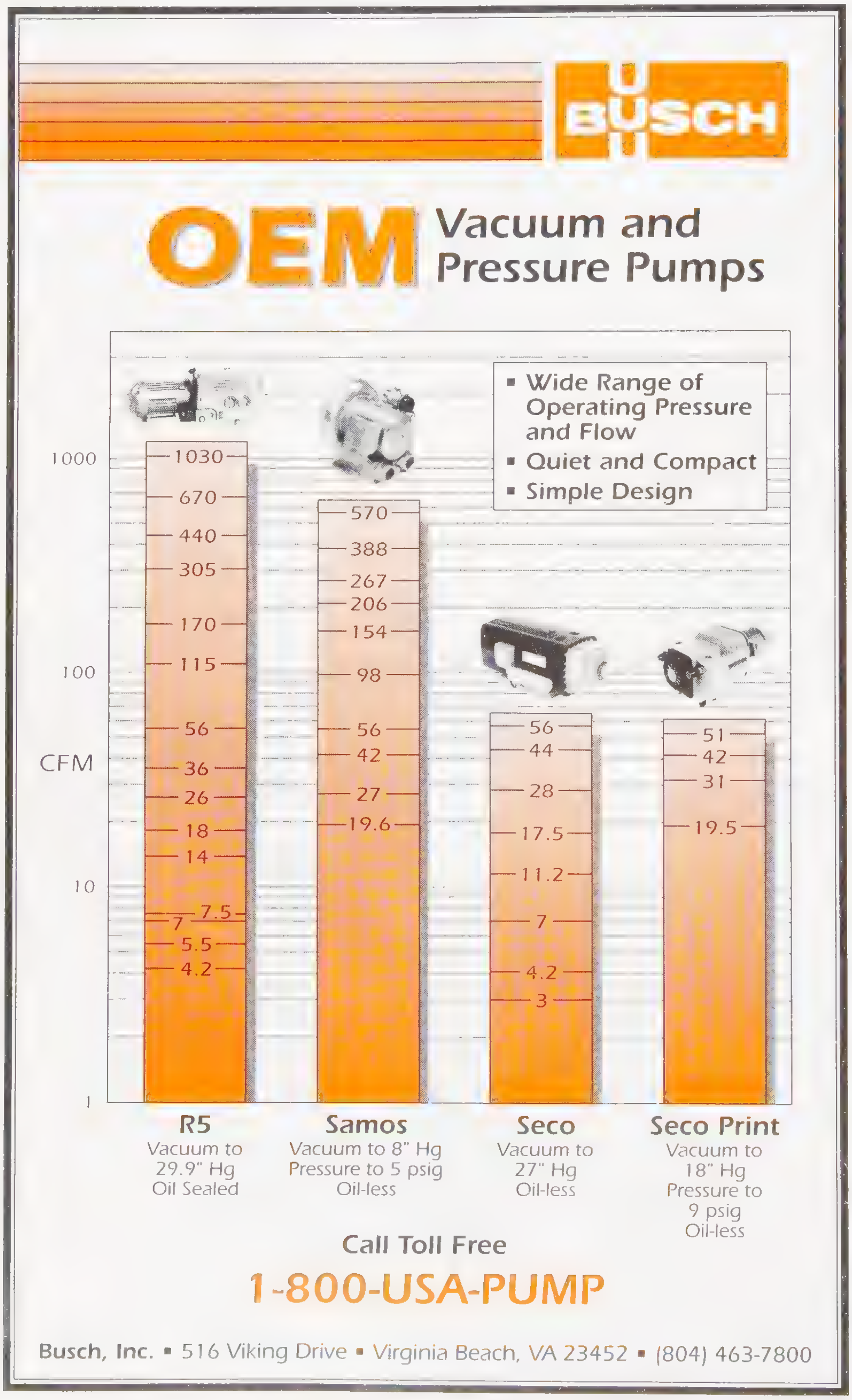
When estimating the speed of booster-operated cylinders, start by calculating oil velocity, v_o, in the lines leading to the cylinder:

$$v_o = \frac{0.3202 q v_p}{A_p}$$

where q = cylinder displacement, v_p = cylinder piston speed, and A_p = internal area of pipe. For efficient flow conditions, oil velocity should not exceed 15 fps.

When air-oil tanks are traversing or resetting the cylinder, oil pressure is equal to air-line pressure — usually around 80 psi. Pressure drop in a low-pressure circuit can materially reduce traverse speed. Sizing the cylinder so that the reaction force is approximately 50 to 60% of the available force at 80 psi usually offsets the effect of the pressure drop.

If calculated oil velocity exceeds 15 fps, system line sizes should be increased to maintain speed. ■


BUSCH

OEM Vacuum and Pressure Pumps

- Wide Range of Operating Pressure and Flow
- Quiet and Compact
- Simple Design

R5
Vacuum to 29.9" Hg
Oil Sealed

Samos
Vacuum to 8" Hg
Pressure to 5 psig
Oil-less

Seco
Vacuum to 27" Hg
Oil-less

Seco Print
Vacuum to 18" Hg
Pressure to 9 psig
Oil-less

Call Toll Free
1-800-USA-PUMP

Busch, Inc. ▪ 516 Viking Drive ▪ Virginia Beach, VA 23452 ▪ (804) 463-7800

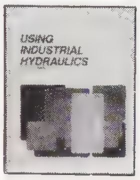
Circle 494

Two Essential Additions To Your Fluid Power Library

Item 2155
Electrohydraulic Servo Systems . . .
James Johnson

This book presents the fundamental concepts of servo control and actuations, feedback, and servo componentry. It explains how electrohydraulic servo-valves work, their characteristics and capabilities, and shows uses and applications of electrohydraulic systems . . . hardbound. . . 170 pages **$27.50**

Item 2161
Using Industrial Hydraulics . . .
T.C. Frankenfield



Beginning with a thorough introduction to hydraulic principles, this book leads the reader through the complete spectrum of hydraulic components and shows how they're used in fluid power systems. Printed in full color—and color-keyed—to clearly illustrate component operation and system functions . . . . .hardbound 400 pages **$48.50**

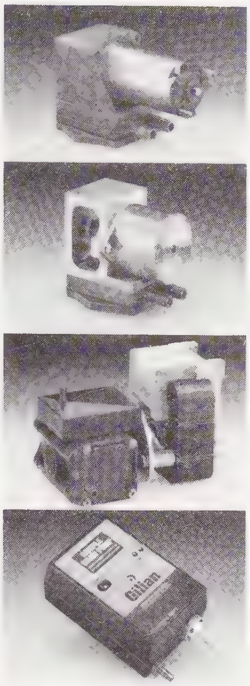
To order, please fill out the coupon below and mail to:

Penton Education Division
1100 Superior Avenue
Cleveland, Ohio 44114
or call
Toll-free 800-321-7003
(in Ohio, call 216-696-7000)

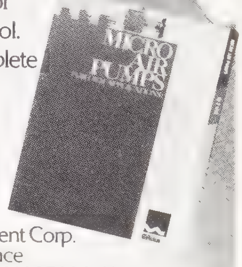
Please send as indicated:
______ copy(s) of Item 2155
______ copy(s) of Item 2161
☐ Check enclosed for postage-free shipment in the U.S.
☐ Bill my company. My purchase order is enclosed.
Charge my: ☐ MasterCard ☐ VISA ☐ American Express
Account# ______
Exp. date ______
Signature ______
Company ______
Name ______
Address (not P.O. Box) ______
City ______
State ______ Zip ______

Penton Education Division
1100 Superior Avenue • Cleveland, Ohio 44114

HIGH OUTPUT MICRO AIR PUMPS



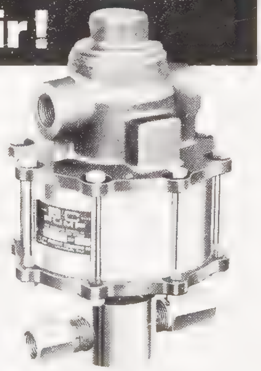
Five models with air flows from 0 to 25 LPM, pressures to 15 PSI. Suction or discharge loads, pulse dampened with constant or variable flow.
Modular construction permits custom configurations at standard prices and optimizes size, weight, and power efficiency for the most demanding, high-reliability applications.
AC, DC, or brushless DC power with sophisticated electronic or pneumatic controllers for precise monitoring of flow and pressure. Adjustable audible or visual alarms indicate loss of flow control.
Individual component pumps to complete systems with Ni-Cad battery packs and custom EMI/RFI-shielded cases.
New color brochure has complete engineering data.



Gilian®
Gilian Instrument Corp.
35 Fairfield Place
West Caldwell, NJ 07006-6206
(201) 808-3355 FAX: (201) 808-6680

Circle 495

70,000 PSI on shop air!

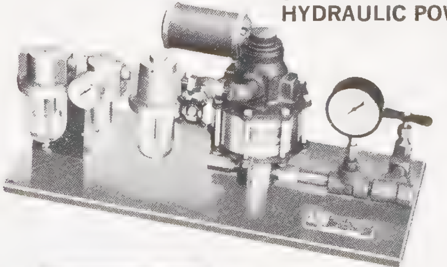


Hydraulic pressures to 70,000 psi are easily and economically obtained — on only 110 psi air pressure — with dependable SC Air-operated Pumps and Power Units.

SC AIR-OPERATED HYDRAULIC PUMPS

Two series adapt readily to a wide variety of applications from simple manual to fully automatic control.
SC 10-500 Series – 13 models from 100 to 42,000 psi hydraulic pressure.
SC 10-600 Series – 13 models from 50 to 70,000 psi hydraulic pressure.

SC AIR-OPERATED HYDRAULIC POWER UNITS



Compact, lightweight, easy to install — SC Power Units incorporate the efficient 10-500 and 10-600 Series Hydraulic Pumps above. A wide range of power units is available to match individual hydraulic pressure requirements, port sizes, and degree of control required.

SC air-operated **Pressure Release Valves** are available in four sizes for hydraulic pressure up to 30,000 psi.

Designers and Manufacturers of Hydraulic Equipment
SC
See your SC representative or write for catalog.
SC HYDRAULIC ENGINEERING CORP.
14032 S. AVALON BLVD. • LOS ANGELES, CALIF. 90061
(213) 321-4536

Circle 496

Get the best hands-on hydraulics training in the industry

At the Vickers Training Center you'll gain the knowledge to improve the productivity of your hydraulics equipment and reduce expensive down-time. You'll study fluid power systems through hands-on training with the latest real-world components. Fluid power trainers and actual components are used to give you a working knowledge of complete hydraulic systems.

You'll learn why each component in the system was selected and how to assemble or disassemble it. Courses cover everything from basic hydraulics and electronics to complete machine systems.

What's more, you can get two full weeks of intensive hydraulics training for less than the cost of some two- or three-day seminars.

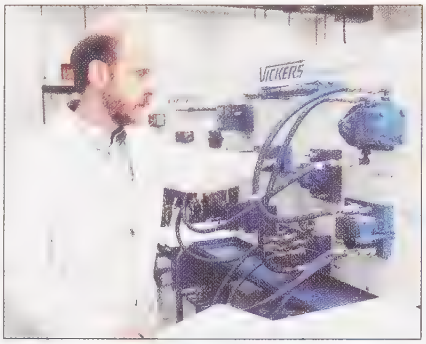
Who Should Attend

- Maintenance personnel
- Design engineers
- Educators
- Company training personnel
- All others who design, specify, sell, use, or distribute fluid power components or systems.

Benefits

- Learn about the latest fluid power technology.
- Get answers to your design, repair and specification questions.
- Understand the design of hydraulic circuits.
- Troubleshoot hydraulic systems.
- Assemble and disassemble hydraulic components.

Circle 497



Basic Industrial Hydraulics

(Two weeks)

Covering the following areas of study:

- Fluid Power Principles
- Basic Troubleshooting
- Fluids
- Filters
- Reservoirs
- Pumps
- Pressure Controls
- Flow Controls
- Directional Controls
- Actuators
- Hydrostatic Transmissions
- Circuits

This course also includes hands-on experience using various components and the Vickers FPT-II trainers. Students have the opportunity to disassemble and assemble products, as well as use them in circuits.

Principles of Proportional Valves

(Three days)

This course is for experienced fluid power system design engineers. Using the Vickers trainers, students work with advanced technology in our hands-on lab.

- Proportional Valves and Electro-Hydraulic Systems
- Electronic Principles for Fluid Power
- Proportional Valves for Open Loop
- Proportional Valves for Closed Loop
- Valve Sizing
- Circuit Applications
- Performance Estimation

Cartridge Valves

(Two and one-half days)

Theory and Operation:

- Study of relief, pressure compensated flow controls, directional controls and more. "Hands-on" circuit construction. Applications and circuit review.
- The principles of both slip-in and screw-in type cartridge valves are taught.
- Students build a multi-segment cartridge valve manifold and operate the unit with the FPT-II trainer.

Electro-Hydraulic Systems

(One week)

This course is designed to help the maintenance person deal with Electro-Hydraulic systems.

- Basic Electrical Principles
- Basic Amplifier Theory
- Control Concepts
- Proportional Valves
- Servo Valves
- Set up and Alignment
- System Troubleshooting

For more information about the best hands-on hydraulics training in the industry, call:

Vickers, Incorporated
Training Center
2730 Research Drive
Rochester Hills, Michigan
48309-3570 U.S.A.
Phone: 313-853-1100
Fax: 313-853-1061

VICKERS

Power modulation and control

Valves are essential elements for controlling fluid system performance.

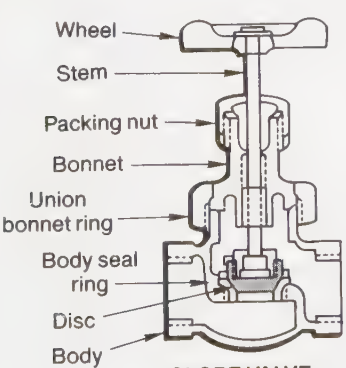
Virtually every fluid-power system requires some type of valve. In a hydraulic system, valves may control pressure, flow to an actuator, or quantity of flow permitted past a given point. Pneumatic valves are similar in design and operation to their hydraulic counterparts, although they may differ in construction.

Trends in the valve industry today include miniaturization of traditional designs and space-saving stackable valves. Compatibility with electronic controls means enhanced valve performance. Manufacturers are also turning to plastics to cut weight while improving lubricity and corrosion resistance. And advanced ceramics are being used for longer life and contamination resistance.

Fluid-transfer valves

Fluid-handling devices are not basically concerned with the modulation of power, but only with the movement of fluid. Choosing a fluid-handling valve used to be easy, because each one had its own area of utility. For on-off, full, or no-flow requirements, ball and gate valves were favored; where tight shutoff was not required, butterfly and slide valves were used. As a result, beliefs were formed which may inhibit the selection of the best valve for a job.

Globe valves are used for throttling purposes and where positive shutoff is required, in sizes up to 6 in. Globe valves have a replaceable plug and seat, and a metal-to-metal seal. Other globe valves are available with elastomeric disc seals. The easy replacement of the plug and seat makes repair simple and inexpensive.



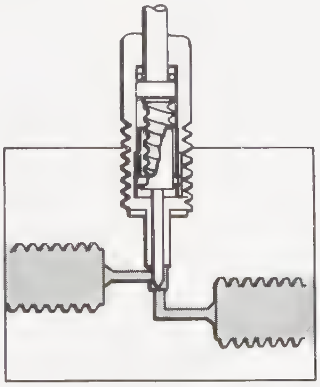
GLOBE VALVE

Pressure loss through a globe valve is somewhat high. Globe valves can be used at high pressures, but the higher the pressure, the more difficult the task of sealing around the stem and the greater the torque required to operate it. Other types of globe valves include:

Angle valves in which the fluid makes a 90° turn as it passes through the valve. Pressure loss through an angle valve is less than that through a conventional globe valve.

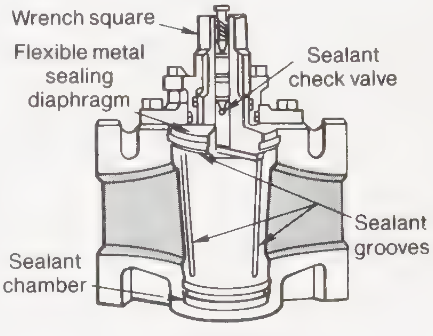
Y-valves that have a reduced pressure drop because the flow passes straight through the valve.

Needle valves which are functionally similar to globes, but they permit a finer adjustment of flow. The end of the stem is pointed like a needle and fits accurately into the needle seat. The seat is typically metal, although elastomeric seats have been used for very fine adjustments. Needle valves are used for very small, accurately adjustable flows.



NEEDLE VALVE

Cock, or plug, valves are the oldest type of valve and still enjoy wide use for on-off service. Plug valves are made with both tapered and cylindrical plugs and in lubricated and nonlubricated models. The early forms of the cock valve used metal-to-metal, nonlubricated seals. Plug valves of this type are still used, but problems of sticking and galling limit their usefulness. These difficulties were largely overcome by the development of the lubricated-plug valve. In this valve, the lubricant is forced into the valve under pressure and is extruded between the plug face and the seat in the body. The lubricant prevents leakage between the plug and body, reduces friction and wear between the surfaces when the plug is turned, and also lifts the plug slightly to reduce the torque required to operate the valve.



PLUG VALVE

A nonlubricated-plug valve may use a tapered plug with a mechanical lifting device that unseats the plug before it is turned to reduce the operating torque required. Or it may have an elastomeric sleeve or plug coating with a low coefficient of rubbing friction. Plug valves are available in sizes as large as 34 in. and in pressure ratings as high as 10,000 psi.

Ball valves represent a modification of the plug valves with a spherical instead of a tapered or cylindrical plug. Advances in materials, primarily polymers, plus improvements in design, have reduced the cost and extended applicability of ball valves.

Ball valves are relatively low in cost; they open and close with one-quarter turn of the handle; provide unimpeded flow through the full bore with minimum pressure drop; and their handle position shows immediately whether the valve is open or closed. In addition, they are easy to clean and repair, and the self-wiping action of the seat as the ball-plug rotates prevents any buildup of contamination to impede full closure of the valve.

Ball valves were developed as on-off valves without much attention given to throttling characteristics. However, design improvements have suited ball valves for some types of flow control, such as throttling the flow of air at differential pressures as high as 1,000 psi. The bulk of the control does not occur with a minor movement of the handle. Only 3% of total flow occurs at 10° of handle travel, 10% at 30°, 30% at 56°, 50% at 70°, and 80% at 82° or 91% of full open. Thus, a ball valve has relatively good throttling characteristics at low flow.

The ball valve is somewhat similar in its operation to the butterfly in that a one-quarter turn opens or closes it, and the valve presents little resistance to the flow of fluid through it. It has two advantages over the butterfly, however. It is available in higher pressure ratings, and it provides a clear passage to the fluid. The passage through a butterfly valve is obstructed by the cross section of the disc and, as the pressure rating increases, so must the strength and thickness of the disc. The pressure drop through the same-sized ball valve is, therefore, less, and the benefit increases as the pressure rating of the valve increases.

Ball valves are available in pipe sizes to 42 in. and in pressure ratings to 7,500 psi. Many designs of ball valves are available to satisfy different requirements, including those with all metal seats and seals, and some that are completely lined with plastic.

Butterfly valves were once used for low-pressure service where complete shutoff was not necessary, and they were not used to modulate flow. Butterfly valves had the advantage of small size, light weight, simple design,

DIVERTING FLOW

Every valve contains a mechanism to modulate or shift flow. This mechanism — typically a spool, poppet, or slide — may be more important than the actuator in determining the successful performance of a valve. Each mechanism type has broad capabilities; in a pinch, any type could be used for nearly all jobs. But specific advantages of each type should be considered to obtain the best valve for a given job.

Spool mechanisms are most common in valves used for industrial hydraulic and pneumatic applications. They are suitable for high pressures, and use short strokes combined with low friction and actuation force. Because these valves depend on close clearances between spool and bore or spool and seal to control leakage, low-leakage varieties may be relatively costly and sensitive to contaminants.

Cartridge valves are simple two-port poppet valves that block, modulate, or allow free flow. The basic components are a sleeve, poppet, and spring that are inserted into a machined manifold block. Normally, four or more valves are used per block, performing a number of functions with a small package. The two main classes of cartridge valves are screw-in and slip-in, which describe how the components are mounted in the block. However, the basic function for either type is the same.

Screw-in valves are smaller and typically used for low-flow applications (below 30 to 40 gpm). They can be considered to be self-contained portless hydraulic valves. The threaded sleeve is merely screwed into the manifold for operation.

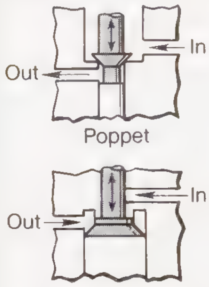
Slip-in valves are used in higher flow applications. The sleeve, poppet, and spring are inserted into the manifold and held in place by a cover that is bolted to the block.

Poppet mechanisms seal on a narrow contact area, either flat or conical, between the poppet and seat. Poppet valves typically provide a large flow area, so they are suitable for hefty flows with minimum pressure drop. Most poppet valves are relatively insensitive to fluid-borne contaminants.

Diaphragm or bellows valves use a poppet mechanism to control flow. They are relatively insensitive to contamination because the diaphragm or bellows acts as a positive stem seal to keep corrosive or dangerous fluids in the valve and out of the operator. These valves are typically used in low-pressure circuits.

Shear valves use a linear actuator coupled with a floating-seal disc that operates in shear across a flat lapped seat. This type of valve provides a self-compensating wear feature: Wiping action along the seal line cleans the seat and seal, and makes the valve highly resistant to contaminants. The seal surface is also protected against erosion from these contaminants. The straight-through flow path provides nearly double the flow of a poppet valve having an equal orifice size.

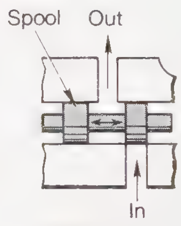
Rotary mechanisms are based on an open-core ball or flat butterfly that rotates to allow flow. Because opening stroke may be long, these valves may be powered by small motors instead of solenoids, and are often used in larger sizes. Flow area is large, pressure drop is low, but basic models tend to have some leakage past the ball unless special seals are built in. Variations on the basic design use PTFE or other polymeric valve seats to produce a tighter seal.



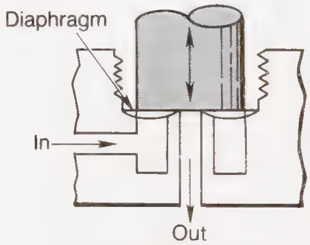
Poppet

Flat-seat poppet

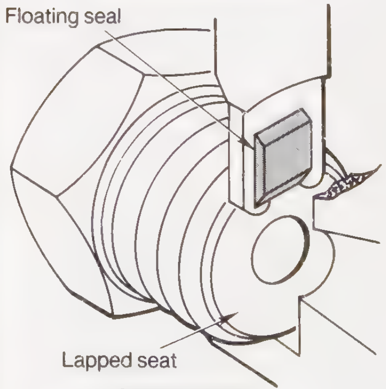
POPPET VALUE



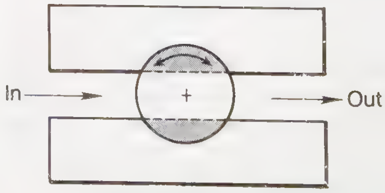
SPOOL VALVE



DIAPHRAGM VALUES



SHEAR VALVE



ROTARY VALUE

EVERYTHING UNDER CONTROL

Clippard

industry's most complete line of miniature fluid power components

Valves

Clippard 2, 3 and 4-way valves, plus toggle valves, heavy duty limit valves, whisker valves, large group of special purpose valves; plus sensors, programmers, electrical switches and solenoids… industry's most complete line. Catalog 189. **Circle 644**

Cylinders

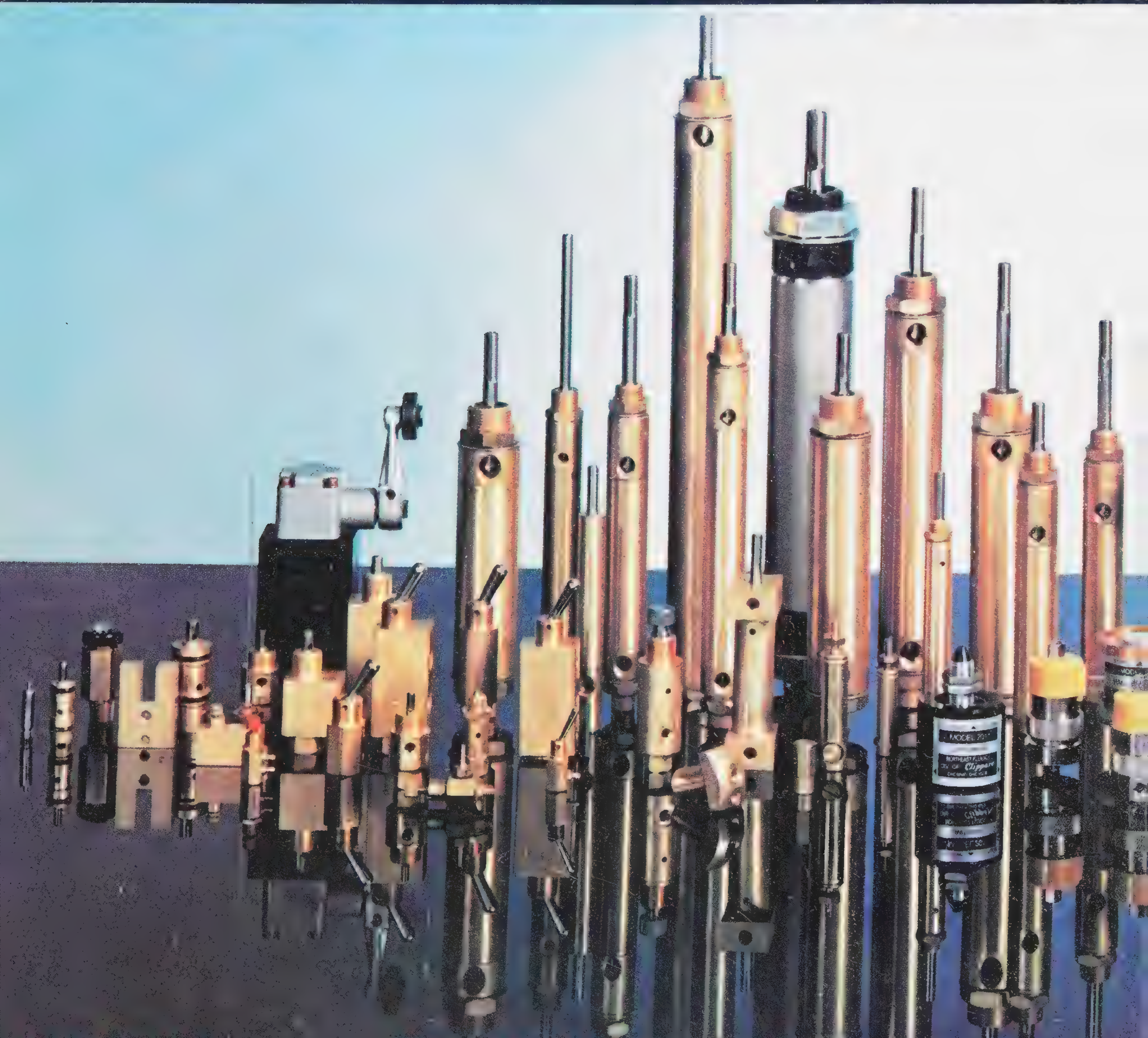
Clippard Minimatic Cylinders… the complete line. From 5/32″ bore to 1⅛″ bore sizes: spring return and double acting models plus full line of associated devices for mounting and use. Catalog 281. **Circle 645**

Modular Components

Modules plug-in for fast, easy circuit building. 52 different types. Valves, controls and sensors in standardized bodies. Octoport porting. Instant plug-in mani-fold sub-plate. Catalog 484. **Circle 646**

Fittings

Clippard minia
fluidic, fluid po
and pneumatic
logic fittings,
clamps, manifo
hose tubing, ga
kets, swivels, a
quick connects
Everything for
automated and
semi-automate
equipment.
Catalog 378.
Circle 647



Leadership

Clippard introduced miniature pneumatic valves, cylinders and fittings to industry more than 30 years ago. No other manufacturer has the same experience or knowledge of miniature components to offer you.

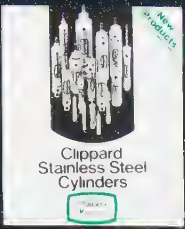
Complete Line

Everything you need for miniature fluid power and air logic control systems is available from Clippard . . . the industry's most complete line. Variety and versatility make your solutions easier.

Quality

Clippard puts quality in design, in materials, in craftsmanship. It takes all three to give you the best products available. Incomparable quality at competitive prices is always assured.

Stainless Steel Cylinders



Clippard quality in low-cost rolled construction stainless steel tube type cylinders. 5/16″, ½″, ¾″, 1 1/16″, 1¼″, 1½″ and 2″ bores. Polished ID 304 stainless tubes; matched aluminum heads; 303 stainless rods. Catalog 784.

Circle 648

Actuators

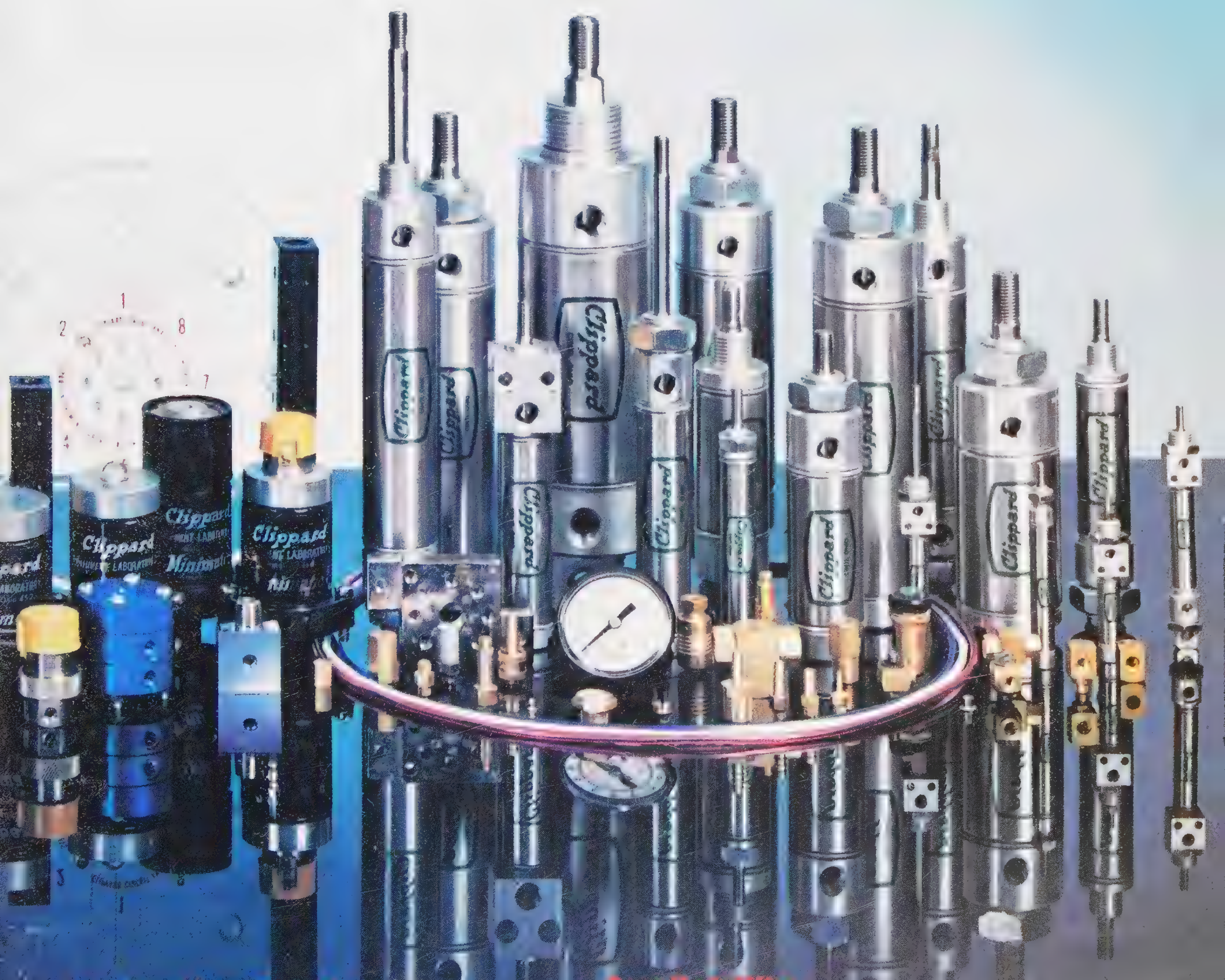
Sleek, smart-looking line of colorful pushbuttons from Clippard has flush, extended, mushroom and key locking models. Choices of bright colors in the most popular types…plus leg-end plates, electric block, and needed accessories. Catalog 884.

Circle 649

Electronic Pneumatic Interface Valves

Accepting signals from low voltage sources, such as controllers, circuits, computer-directed control systems… Clippard Mini-matic Interface Valves convert the electronic signals into high pressure (100 psi) pneumatic outputs. Twelve basic models. Catalog 984.

Circle 650



Innovative Design

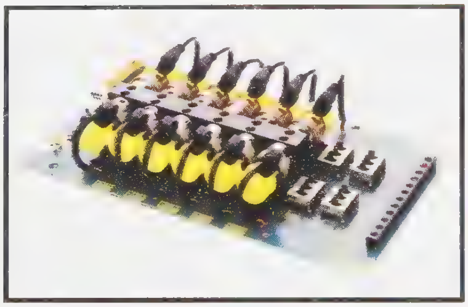
Each year, Clippard, the pioneer in miniature fluid power, introduces new products and concepts. Electronic/pneumatic interface valves, plug-in modular components . . . and now subminiature stainless steel cylinders.

Availability

Clippard products are sold by more than 130 stocking distributors worldwide. These dedicated fluid power professionals are available to assist you in saving time and money with product applications.

Clippard
PNEUMATICS/ELECTRONICS
A FAMILIAR INTERFACE!

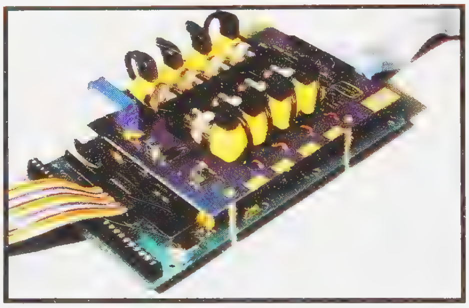
NEW electronic/pneumatic interface products



CLIPPARD ELECTRONIC MANIFOLD CARDS provide new convenience in interfacing electronics and pneumatics. They are fast mounting, completely assembled banks of Clippard EV/ET valves. Cards hold either 8 or 12 valves, manifold mounted for use with a single air supply. Circuit boards are fully wired, with each valve switchable. Choice of valve types. 6, 12 or 24 VDC. No card rack needed.

ASK FOR CATALOG 1086

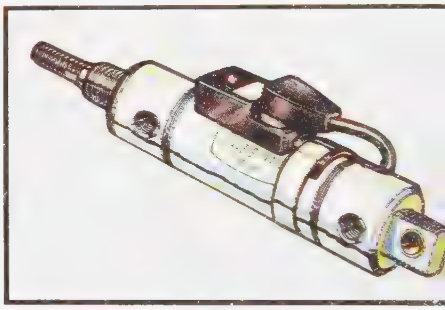
Circle 651



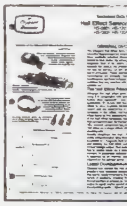
COMPUTER INTERFACE LOGIC (Clippard CIL-1) is a new microprocessor based system for machine or process control. System mates programmed inputs to powerful pneumatic or electronic outputs, using Clippard EV/ET valves, plus the programmability of a CMOS microprocessor. Fast programming, accurate control, 24 I/O combinations plus interrupts, counter and watchdog timer. Program using a dumb terminal, P/C or hand held programmer.

ASK FOR CATALOG CIL-1

Circle 652



HALL EFFECT SWITCHES sense piston po
tion in pneumatically actuated Clippa
Stainless Steel CILinders™. Mounted on t
outside of the cylinder, switches are activat
by internal piston magnets. Resulting signals provide feedback to Clippard EV/ET valves, or to CIL-1 system control. Operation sequence steps can be verified, and used to control further downstream activities.



ASK FOR TECH DATA SHEET 8

Circle 653

For the name of the experienced Clippard distributor near you,
as well as complete detailed product catalogs, write or phone us today!

from a name you can trust...

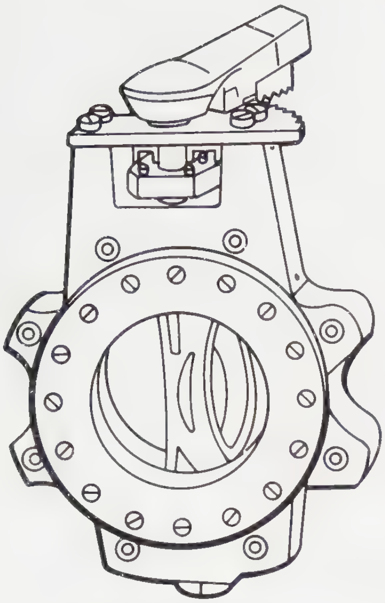
Clippard Minimatic®

Clippard Instrument Laboratory, Inc., 7386 Colerain Rd.,
Cincinnati, Ohio 45239, USA Phone: (513) 521-4261 Fax: (513) 521-4464

Bulletin 685–R1
5M 489

©1985 Clippard Instrument Laboratory, Inc.

Printed in US



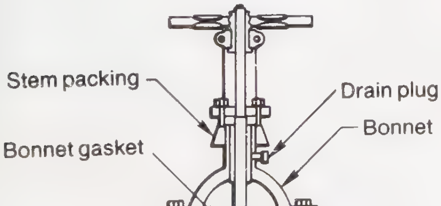
BUTTERFLY VALVE

and low-pressure drop. They also required only a one-quarter turn to change from closed to the fully open position.

Today, butterfly valves retain their traditional virtues. But capabilities have been greatly extended by offset discs and polymeric seals. These and other design innovations have enabled butterfly valves to be used for throttling, tight sealing, and withstanding pressures as high as 1,200 psi while retaining many traditional advantages.

A modern butterfly valve may include a pressure-tight resilient seat and an angularly offset disc. Other butterfly valve designs use a hard seat and an O-ring or piston ring around the disk to seal. Butterfly valves range in size from small to enormous, and are well suited for large flows of gases, liquids, or slurries.

Gate valves include wedge and double-disc valves. Both are typically used in a fully open or fully closed position because close regulation of flow is not possible.



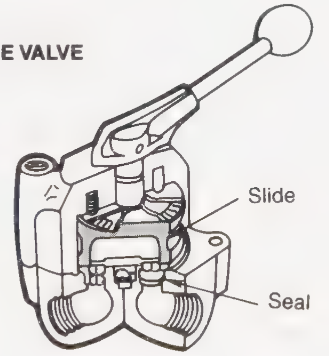
GATE VALVE

A gate valve can be used for throttling only when the valve is in an almost shut position, where most of the flow reduction occurs. The small, crescent-shaped aperture causes a high flow velocity that can erode seat faces. Repeated movement of the disc near the point of closure against upstream pressure can create drag between the seat on the downstream side and may gall or score the seat faces. In addition, the high-velocity flowing liquid impinging against a partially open disc or wedge produces vibration that can damage seating surfaces and score the downstream side.

Nevertheless, a gate valve is excellent for service that requires either full or no flow. It has essentially no flow restriction when fully open. The flow area at the point of control is equal to the full cross-sectional area of the line. Because flow is straight through the line, pressure drop across a gate valve is only about 1/50 that of a globe valve of comparable size. However, globe valves are preferred if lines must be opened and closed frequently.

Slide valves consist of one or two discs, usually without a spreading mechanism. Fluid pressure on the disc presses its surface against the seat for closure. Some slide valves are made with soft seats to reduce the required manufacturing tolerances for a better seal. Slide valves can be made quite thin for jobs where space is a problem. Ordinarily, slide valves are used to control flows of low-pressure fluids where tight shutoff is not required. They can handle straight-through flow of gases, liquids, slurries, and fluidized solids. Ordinary slide valves are made in sizes from 2 in. and up, and are used at pressures to 400 psi.

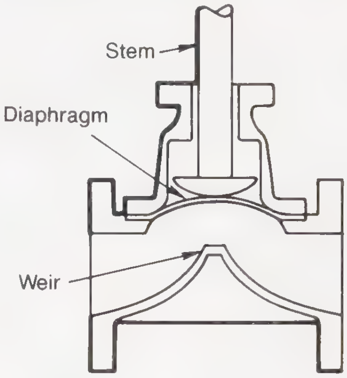
SLIDE VALVE



The development of a seal that operates in shear has permitted production of special slide valves that operate at pressures to 10,000 psi while retaining the slide-valve advantages of quick opening or closing, unobstructed flow, and low operating torque. This seal principle permits use of erosion-resistant material in the port areas, so these valves show excellent throttling characteristics without undue seal wear.

Lift valves, commonly referred to as control valves, are generally constructed with two ports in parallel. They are made in sizes to 16 in., to give any required relationship between percent of opening (stem travel) and percent of full flow. Complete shutoff is almost impossible.

Diaphragm valves consist of a body, bonnet, and a flexible diaphragm that is pushed down by the stem to effect closure. The principal advantage of this type of valve is that the stem seal is eliminated. Diaphragm valves are used primarily for handling viscous fluids, slurries, or corrosive fluids. They can be used to throttle flow, but because of the large shutoff area, low-flow throttling characteristics are not good. The effective operating temperature range is limited by the properties of the diaphragm and run from −60 to 450°F. Pressure ratings run to 300 psi.



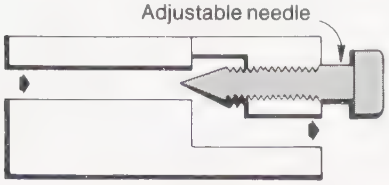
DIAPHRAGM VALVE

Flow valves

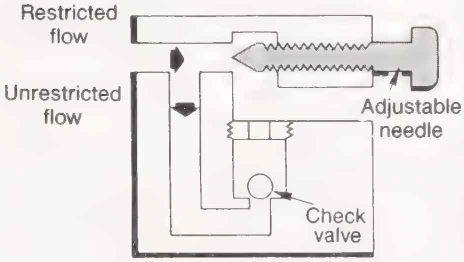
Flow is controlled by either throttling or diverting it. Throttling involves reducing orifice size until all of the flow cannot pass through the orifice; bypassing involves routing part of the flow around the circuit so that the actuator receives only the portion needed to perform its task. If the flow inlet to an actuator is controlled, the circuit is said to be a "meter-in" system. If actuator outlet is controlled, it is called a "meter-out" circuit. When that part of the fluid being diverted to the reservoir or another part of the circuit is controlled, it is said to be a "bleed-off" system.

Noncompensated flow controls are simple valves that meter flow by restricting or throttling. The amount of flow that passes through an orifice and the pressure drop across it are directly related. As pressure increases, valve flow increases.

Common noncompensated valves are adjustable needle valves; flow through them varies with fluid viscosity and pressure across the valve. Usually, a needle valve is paired with a check valve that offers resistance to flow in one direction only. The combination permits flow to be adjusted in one direction, with free flow upon reverse. This type of two-valve combination is typically called an adjustable restrictor valve.



NON COMPENSATED
FLOW CONTROL

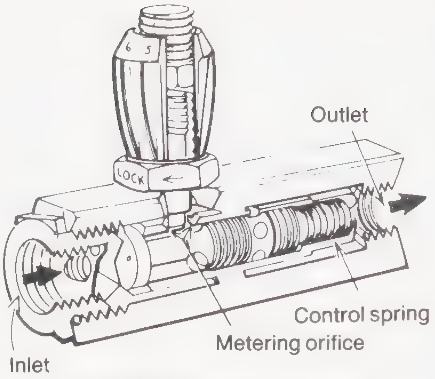


ADJUSTABLE RESTRICTOR VALVE

For some tasks, adjustability is either unimportant or potentially harmful. For such tasks, a fixed resistor valve can be used. Basically, it consists of a check valve with an orifice embodied in the valve. Some fixed restrictors make provision for disassembling the valve and changing the orifice; others have no such provision. In either type, the orifice is not changed during circuit operation so the valve is considered nonadjustable.

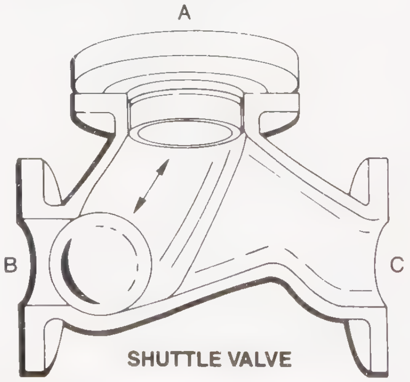
Both fixed and variable restrictor valves are simple, reliable, and inexpensive. They do not accurately control flow if load or viscosity changes. They can be used in any circuit, using any metering method. Experts recommend these noncompensated valves when accuracy is not important, when heat generation through power loss can be tolerated, and in such circuits as gravity lowering, where they can be used efficiently.

Pressure-compensated flow controls maintain nearly constant flow despite variations in circuit pressure. Like the noncompensated units, they incorporate a metering orifice. Flow pressure drop across this orifice is used to shift a balanced spool against a control spring. This spool movement is used to maintain a constant pressure drop across the orifice, which in turn, produces a constant flow. Pressure drop across the orifice is relatively low.



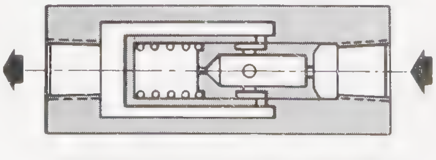
PRESSURE COMPENSATED
FLOW CONTROL

Check valves use a ball or poppet to prevent flow in one or more directions. In two-port valves, the ball or poppet is usually lightly spring loaded against one of the ports. In three-port valves, or shuttle valves, internal ridges guide the ball between ports. In the version shown, flow is permitted from port A to C or from port B to C, but not from A to B or B to A.



SHUTTLE VALVE

Restrictive flow regulators work like an automatic variable orifice to control flow by throttling or restricting. Compensator spool movement blocks fluid flow through the valve. Flow passing through the metering orifice is accompanied by a pressure drop that is applied to each end of a balanced spool. The resulting force imbalance moves the spool against the control spring. Spool movement progressively blocks off flow area restricting or throttling flow through the valve.



RESTRICTIVE FLOW REGULATOR

Restrictive flow regulators are ideally suited to constant-pressure closed-center circuits and meter-out situations. Experts say they are the only pressure-compensated flow control that can be used in these applications. They are also recommended for gravity lowering devices where uniform lowering speed is required regardless of the load.

FLOW VALVES FOR SIMPLE CONTROL

Pneumatic cylinders operating on plant air provide a simple and low-cost method for producing moderate-to-large forces in a convenient package. Further, controls for air cylinders are typically uncomplicated and inexpensive.

A basic combination of cylinder and four-way valves may provide all the control that is necessary in many simple applications. However, air is compressible, and in some cases, the resulting "spongy" feel is detrimental. A practical and economical method for minimizing sponginess is to partially restrict flow from the cylinder exhaust port. This technique, called metering out, is done by installing pneumatic flow-control valves in both cylinder ports.

Flow-control valves consist of two basic elements, a check valve and an adjustable restrictor, combined in a single housing. Air leaving the cylinder closes the check valve, and exhausted air must pass through the restrictor. This meters outflow and causes a slight rise in internal pressure. Flow-control valves permit a form of speed control with smoother motion during translation and reduced shock load at the end of stroke.

Another application for flow-control valves is impact control on overrunning loads. Here, the combination of moving parts inertias and driving force from inlet pressure causes high impact forces on the extending stroke. Flow controls are recommended on noncushioned cylinders where maximum speed is not a prime concern. A properly adjusted flow-control valve at the exhaust port converts destructive impact into a gentle stop.

In high-speed applications, installing cylinders with built-in cushions is preferred. Cushioned cylinders permit rapid piston movement, except near the end of stroke, where the functional equivalent of a flow-control valve comes into play and damps impact.

ASCO® Red-Hat® and Red-Hat II™ Solenoid and Air Operated Valves

We've added a whole new concept in solenoid valves, called Red-Hat II, to the world's most-specified, most-preferred line. Many features normally available only as extra-cost options are now Red-Hat II standards. For example, high-temperature Class F coils completely encapsulated in molded epoxy. They provide enclosure protection up to Type 4X, and even include built-in conduit hubs with strain relief. All standard.

With thousands of standard ASCO valves available, in either traditional Red-Hat® or new Red-Hat II™ designs, chances are we have precisely what you need. And you can do even more with our options. For example, you can specify Explosion-proof enclosures, Class H coils, spade or screw terminals, junction box or panel mount constructions, and many others.

And ASCO's nationwide network of more than 250 stocking distributors keeps technical assistance, sales and service always within easy reach.

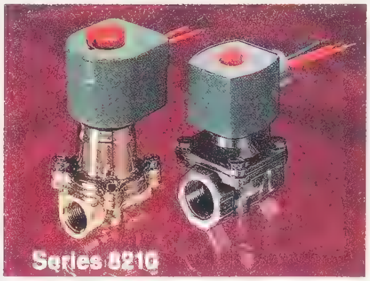
Find the valves you need on the next few pages, then call for more information . . .

Automatic Switch Co.
FLORHAM PARK, NEW JERSEY

ASCO® Red-Hat® an

2 WAY VALVES

These shutoff valves have one inlet and one outlet. Operation is either Normally Cl



Pilot Operated General Service Solenoid Valves

3/8″ to 2-1/2″ N.P.T., diaphragm or piston constructions.

Pilot Operated Slow Closing Solenoid Valves

3/8″ to 2-1/2″ N.P.T., anti-water-hammer valves to protect your system from shock waves.

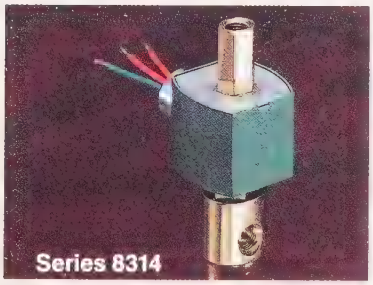
Direct Acting Sub-Miniature Solenoid Valve

1/8″ N.P.T. valves for in-line or gro mounting. Also available for 3 wa operation.

Circle 502

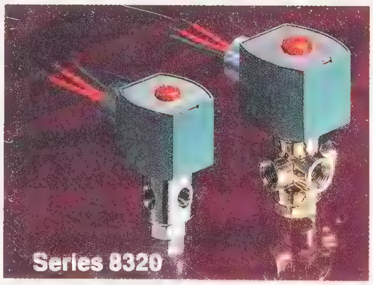
3 WAY VALVES

These valves have 3 pipe connections and two orifices (when one is open, the other is closed.) They alternately apply pressure to and exhaust pressure from a diaphragm valve or single acting cylinder.



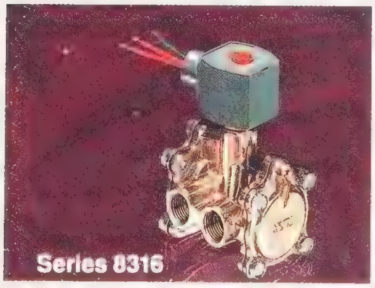
Direct Acting General Service Solenoid Valves

Compact, 1/8″ and 1/4″ N.P.T. valves for handling air, water and light oil.



All-Ports-in-Body Solenoid Valves

1/8″ and 1/4″ N.P.T. valves designed primarily as pilots for larger valves.



Pilot Operated General Service Solenoid Valves

Rugged, 3/8″ to 1″ N.P.T. valves for handling air and water.

Circle 501

Plastic Body Direct Acting Solenoid Valves

1/4″ compression-connection valves for liquid food products, air and water.

4 WAY VALVES

These valves have fou five pipe connections: on pressure, one or two exha and two cylinder. In one p tion, pressure is applied t

Direct Acting General Service Solenoid Valves

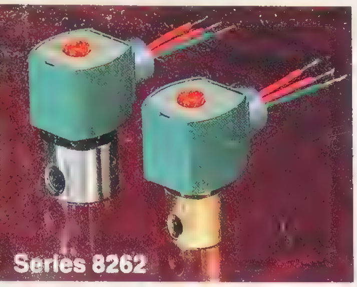
1/4″ to 3/8″ N.P.T. valves for pressures to 125 psi. Single or dual solenoid.

Pilot Operated General Service Solenoid Valves

1/4″ to 1″ N.P.T. for air, water anc light oil. Dual solenoid version maintains position when de-energized. **Circle 503**

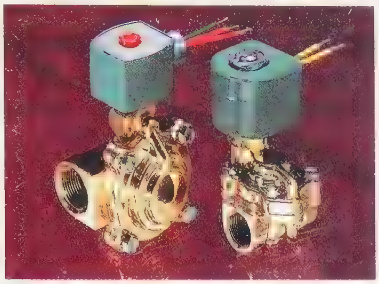
Red-Hat II™ Valves

osed when de-energized) or Normally Open (open when de-energized.)



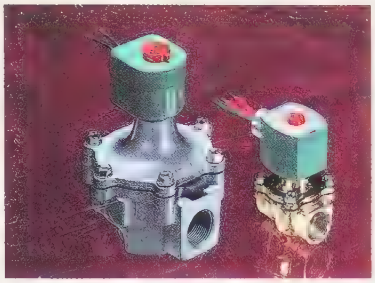
Direct Acting General Service Solenoid Valves

1/8″ to 3/8″ N.P.T. valves to handle a broad range of applications.



Steam/Hot Water Solenoid Valves

Many designs in 1/4″ to 2-1/2″ N.P.T. sizes for handling hot water and steam at temperatures up to 353°F. Also available for 3 way operation.



Low, Medium & High Vacuum Valves

1/4″ to 2″ N.P.T. for vacuums from 760 Torr to 10^{-6} Torr and below.

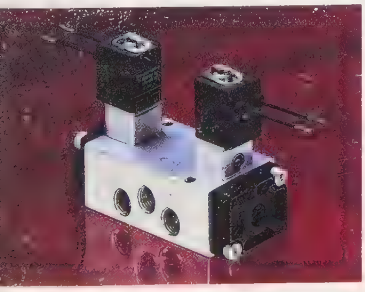
Circle 505

2, 3 and 4 WAY SPECIAL PURPOSE VALVES

ne end of the cylinder and
ne other exhausts. When the
alve shifts to the other posi-
on, pressure and exhaust
re reversed.

Redi-Air® Miniature Slide Valve

1/8″ and 1/4″ N.P.T. valves provide C_v adjustable from .10 to .80. Unique design tosses aside dirt and lubricated air residue.

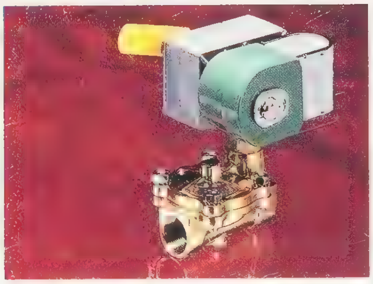


Redi-Air® ISO-Base Directional Control Valves

1/8″ to 3/8″ N.P.T. with in-line, sub-base and manifold mount designs. Solenoid or air, single or dual powered.

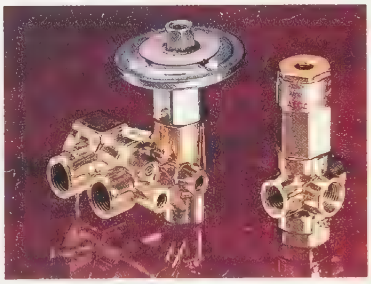
Circle 504

■ Request our latest catalog for more information on these and other ASCO solenoid and air operated valves.



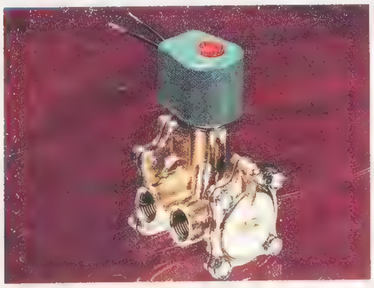
Manual Reset Valves

These valves prevent inadvertent start-up of critical processes. Once tripped, they must be manually reset to resume operation.



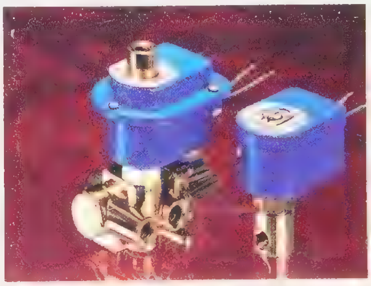
Air Operated Valves

1/4″ to 2″ N.P.T. bodies with air operators replacing the solenoids. Many unique features.



Long Life Valves

Standard ASCO valves modified to extend cycling life and eliminate solenoid "click" when handling dry air and gas.



Intrinsically Safe Valves

Special solenoids operate on power so low that a spark or thermal effect cannot cause an explosion.

Circle 506

ASCO® TRI-POINT® Pressure and Temperature Switches

Industrial, Compact and Miniature designs to meet your needs precisely... stocked by over 100 authorized distributors from coast to coast!

ASCO's unique concept of separate switch and pressure or temperature transducer units makes it possible to offer almost 20,000 Tri-Point variations.

Industrial Switch Units

You can choose from adjustable and fixed deadband types • Two-stage (dual function) types • Manual Reset operation • Differential pressure controls • Vacuum types • Pressure ranges from 12″ H_2O to 8,000 psig • Temperature ranges from −60°F. to +640°F. • General Purpose, Watertight, and Explosion-proof enclosures.

Compact Switch Units

The same big features found in our Industrial Switches are also offered in smaller packages: the Tri-Point Compact Line. They're available Open Frame, or with Type 1 General Purpose or Type 4 Watertight enclosures.

Pressure Transducer Units — Over 50 different transducer units which mate to our Industrial or Compact switch units encompass 20 pressure ranges from vacuum to 8,000 psig: available with aluminum, brass or stainless steel wetted parts.

Temperature Transducer Units — These mating units have copper or stainless steel sensors, either direct mount or capillary-and-bulb, and are available in ranges from −60°F. to +640°F. **Circle 508**

For more information, request Catalog 505.

ASCO Miniature Pressure Switches like the going tough!

Factory-set and tamper-proof ASCO J Series Miniature Pressure Switches are sealed with specially compounded epoxy that maintains its integrity from −40°F. to +250°F. They resist water, dust and salt spray. High rate springs and low mass material provide vibration resistance up to 10 Gs.

ASCO H Series switches provide many of the same features for normal environments and are field adjustable.

For more information, request Catalog P-7083.

Circle 507

ASCO/Angar Valves are microminiature, but their technology isn't.

These 2 and 3 way valves have stainless steel bodies and Teflon* seals. Pinch and isolation models are also available. Power requirements are as low as .65 watts and response time is measured in milliseconds. Any standard valve can be customized to meet specific requirements. **Circle 509**

For more information, request Catalog A.

*DuPont Co. trademark

ASCO can also meet your electrical power control needs with innovative products for:

- Prime Power
- Emergency/Standby Power
- Cogeneration
- Peak Load Shaving
- Remote Control Lighting
- Energy Management

ASCO® Automatic Switch Co.
50-60 Hanover Road, Florham Park, N.J. 07932

FOR TECHNICAL ASSISTANCE
Phone: 1-201-966-2019

FOR FASTEST SERVICE
Fax: 1-201-966-2628

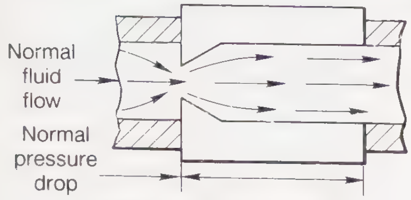
FOR PRODUCT LITERATURE OR LOCATION OF YOUR NEAREST STOCKING DISTRIBUTOR

Call, toll-free
1-800-972-ASCO

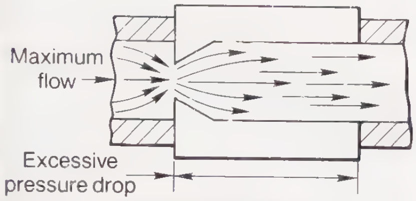
V6614

©Automatic Switch Co. MCMLXXXVIII

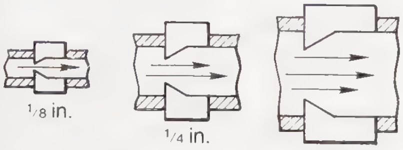
DETERMINING FLOW CAPACITY



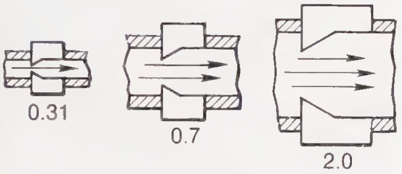
NOMINAL FLOW RATING



MAXIMUM RATING



SIZE RATING



C_v RATING

Valve size can be related either to size of piping connections or to flow capacity. Pipe-size designations (⅜ in., for example), although still useful, do not provide an adequate indication of valve performance. Valve flow capacity (for example, 50 gpm) refers to the amount of fluid that can be handled by the valve. It can be expressed as a "nominal" or "maximum" rating.

Nominal flow rating refers to a flow rate obtainable with relatively low pressure drop — the total reduction in pressure through the valve, including losses in all passages. The nominal rating quoted by valve makers is often the hydraulic flow capacity that creates a 50 to 60-psi pressure drop through the valve.

Maximum rating refers to the maximum flow a hydraulic valve can control without malfunction. For example, a valve with a 30-gpm nominal rating functions properly with flows to 50 gpm, but rated minimum pilot pressure may be insufficient to shift the valve. When a valve is used within reasonable limits above its nominal rating, pressure drop increases directly with the square of the flow.

Size ratings are only approximate. A valve designated as ¾ in., for example, is not necessarily limited to use with only ¾-in. pipe. Improvements in valve construction have reduced the significance of pipe-size ratings. Hydraulic valves that were originally able to pass 1 to 2 gpm were called ⅛-in. valves, indicating the pipe size recommended for the flow. A 4 to 6-gpm valve was called a ½-in. valve. Now, valves of these same sizes can pass considerably higher flows. In most cases, mounting dimensions have remained the same and the same size designation has been retained for identification.

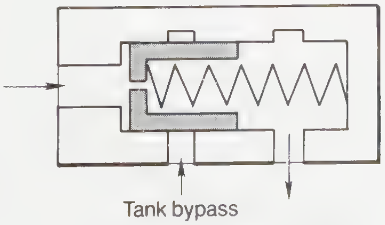
C_v ratings for pneumatic valves are used in addition to port size designations. Although many methods have been used for specifying pneumatic valve size, many manufacturers have standardized on a technique involving flow coefficient C_v. Typically, these values are published in the form of charts for specific valves. To use such a chart, only the required downstream pressure and the available upstream pressure need be known. A look at the chart quickly indicates what the flow rate must be to obtain such a pressure ratio.

Although this method of sizing pneumatic valves provides an accurate indication of steady-flow capacity, it often does not provide enough data for determining whether a specific valve will satisfy a specific circuit response requirement. For instance, valve-shifting time and actuator-exhaust or fill time might be large enough to introduce errors into valve-sizing calculations. Accordingly, experts recommend that such factors as pipe size, length, and number of bends be considered; if necessary, C_v values for these can be computed and entered into the calculations. A more reliable approach is to build and test a prototype system.

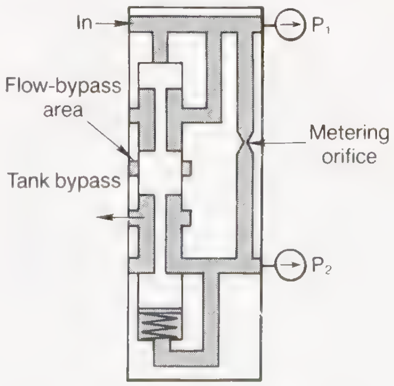
Bypass flow regulators control flow by diverting excess pump output to the reservoir. The same basic control orifice and compensator spool are used as in the restrictive flow regulator. But, instead of restricting flow through the valve, spool movement diverts or bypasses excess flow to the reservoir.

These regulators are used exclusively in variable-pressure open-center circuits, and only as a meter-in device. The resulting pump or supply pressure is slightly higher than that required to do the work, and automatically changes with load. Bypass flow regulators cannot be used as meter-out devices in any circuit or as meter-in devices in constant-pressure circuits. The ability of these valves to accept all flow supplied to them excludes them from these applications.

Combination bypass and restrictive flow regulators are a combination of the first two mentioned. They control flow by both restricting and bypassing, permitting full use of both regulated and bypass flow. Flow through a controlled orifice produces a pressure that shifts a compensating spool. Movement of the spool first uncovers the bypass-flow area. If bypass-circuit pressure is greater than regulated-circuit pressure, the spool moves farther to restrict or throttle the controlled flow. Regardless of pressures in either circuit, the combination flow regulator maintains a constant con-



BYPASS FLOW REGULATOR



COMBINATION FLOW REGULATOR

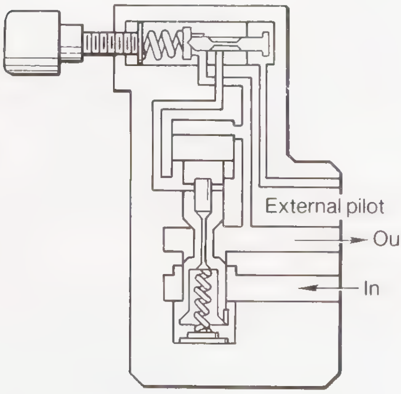
trolled flow. Full pump flow is at the higher of the two pressures.

Combination flow regulators are sometimes called "priority" valves. They establish priority flow to the control circuit and bypass to the secondary circuit only when the flow demands of the primary circuit are met. If pump supply is less than that required at the regulated port, all flow goes to the regulated port and none is diverted. This type of combination valve is ideally suited for meter-in speed control in open-center fixed-displacement pump circuits.

Pressure valves

The primary concern in fluid-power circuits is to control either pressure level or the rate of flow. In theory, most flow-control valves could be used to control pressure. If orifice size, supply flow, and fluid viscosity are fixed, pressure remains constant; if any one of the three varies, pressure varies. Typically, however, such valves produce only the crudest kind of pressure control. For more accurate control, several types of pressure-control valves have been developed; they are categorized by the function to be performed.

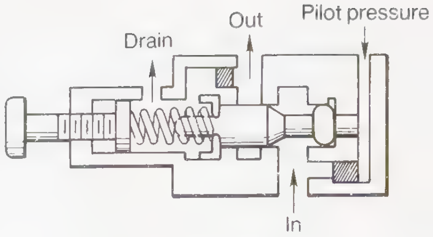
Counterbalance valves resist movement or balance the load being held by a cylinder or motor. These valves, by controlling pressure, provide excellent dynamic control. If they must hold the load for long periods, experts recommend that they be supplemented with a pilot check valve, which has better static-holding capabilities.



COUNTER BALANCE VALVE

Diverting valves (known in the mobile industry as "sequence valves") establish flow priorities within a circuit by using a pressure-actuated three-way valve with controls. The valve assembly directs pressurized fluid to a primary port until a predetermined pressure level is reached. At this value, flow is diverted from the primary outlet to a secondary outlet. Flow continues at the secondary as long as the pressure in the primary outlet is maintained. Pressures can be cascaded through several steps if needed.

Sequence valves are used to determine the sequence of machine operations by sensing pressures other than maximum. These normally closed valves permit flow between inlet and output ports when the pressure reaches preset levels, and can be fitted with free-flow checks to permit flow in the opposite direction.



SEQUENCE VALUE

Many sequence valves have two or more spools or poppets that must be actuated before flow can pass through the valve. Typically, a signal shifts the control spool, ensuring that a certain

CARTRIDGE VALVES BOOST PERFORMANCE

The prime advantage in using cartridge valves is the ability to control individual flow paths, something that cannot be done with conventional spool valves. Spool valves are fixed timing devices: The spool always travels across the pressure and cylinder ports in the same manner, always giving the same opening and closing relationships.

Using a cartridge valve in each flow path allows for separate timing, giving more precise system control. Also, each can be sized for the individual flow required. Spool valves, on the other hand, must be sized for the largest flow.

Lower initial cost is not a particularly strong argument in deciding whether to use cartridge valves. In the 40 to 50-gpm flow range and below, cartridge valves are more expensive than spool valves if simply used for directional control with no special functions. At higher flows, or with additional functions such as relief, reducing, or check, the cost advantage leans toward cartridge valves. The incremental cost of adding additional components to the manifold is less than the cost of adding new components and plumbing to a conventional system.

Another advantage over spool valves is faster response; up to four times faster than in a conventional system. Cartridge valves need only to be cracked open to allow flow, spools must be moved a certain distance before a flow path is opened.

Despite the faster response time, cartridge valves also are better at controlling shock caused by rapid changes in flow rate. Generally, shock has a detrimental effect on mountings, fittings, cylinders, and overall equipment life. The precise control of opening and closing timing that cartridge valves permit can effectively eliminate shock.

The compact design of the cartridge/manifold arrangement is a prime advantage when size or weight is at a premium. Not only are the valves contained within the manifold, most of the plumbing is also internal. In fact, in a cylinder control system, the only external lines are those to tank, pump, and the actuator. A number of hoses and fittings are eliminated, simplifying the system and reducing the number of potential leak points.

In addition to the manifold setup being a cleaner, more compact package, it can also be easier to maintain. In troubleshooting a problem, maintenance personnel have a couple of options. If the problem is apparent, the cartridge valve in the particular circuit is simply replaced. Unlike a conventional spool valve system, there are no hoses and connectors to contend with. If the problem cannot be isolated, downtime can be minimized by replacing the entire manifold, and repairing the hydraulics away from the machine. Also cartridges are typically low-cost items, further reducing service costs.

Cartridge valves are better suited to high pressures than spool valves. Spool valves are limited to pressures of about 2,500 to 3,000 psi. At higher pressures, spool deflection can cause binding. Clearances can be increased to prevent this condition, at the price of increased bypass leakage. In addition, higher forces on the spool translate into higher forces required to shift the spool. Larger solenoids, or solenoid/pilot control are needed, which increases complexity, cost and shift time. For these reasons, high pressure spools are not prevalent, except in small sizes. On the other hand, the limiting pressure factors in cartridge valves are manifold body materials and the control valve.

Directional Control Valves

Standard shut-off, 3-way, 4-way and dual pressure types available. Choose from operating ranges of vacuum to 15,000 psi for air, water and hydraulic oil service, with a choice of operation methods — manual, single and dual solenoid, cam, air, hydraulic or electric motor. Wetted materials include stainless steel, aluminum, pvc, brass, etc. For pipe sizes ¼″ through 1½″ Barksdale is America's leading supplier of standard and custom engineered high pressure valves for the fluid power industry. For more information, contact Imo Industries Inc., Barksdale Controls Division, 3211 Fruitland Ave., Los Angeles, CA 90058, (213) 589-6181.

Barksdale Circle 510

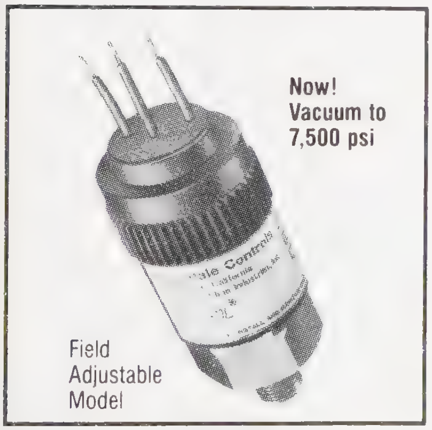
How to Select Pressure Switches

This bulletin outlines a step-by-step method of selecting the correct choice of pressure or vacuum switches for your set of conditions. The four basic sensing methods (spanning the industrial range of application from 30 inches of mercury vacuum to 18,000 psi) are cross-sectioned and explained for your better understanding. There is also a section which discusses the risks in using light-weight home appliance type switches for industrial projects. For your free copy, write Imo Industries Inc., Barksdale Controls Division, 3211 Fruitland Avenue, Los Angeles, CA 90058, (213) 589-6181.

Barksdale Circle 514

Single and dual setting units for adjustment ranges from −50° to +450°F. The close-coupled liquid filled sensor actuates an instrument quality snap action switch at the desired set point. The setting is field adjustable with a dial knob, calibrated in Centigrade as well as Fahrenheit. A tamper-proof cover protects the setting. Wetted materials are 316 stainless steel or brass. NEMA 4 (watertight) or NEMA 7, 9 (explosion-proof) housings have removable cover for easy wiring to internal terminal board. For more information, contact Barksdale Controls Division, Imo Industries Inc., 3211 Fruitland Ave., Los Angeles, CA 90058, (213) 589-6181.

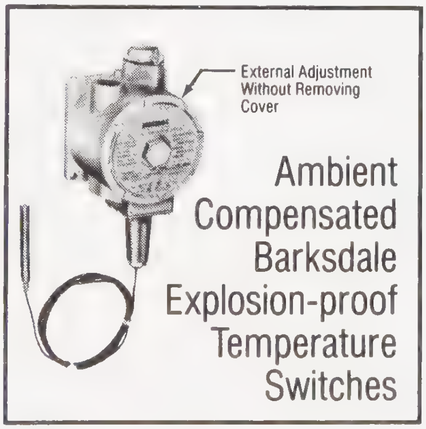
Barksdale Circle 511



Maxtrol™ Pressure Switch: New From Barksdale

Expanded to include a diaphragm piston version, the NEW compact Maxtrol™ pressure switch is now available in eleven pressure ranges, from Vacuum (30″ Hg.) to 7,500 psi. Factory set and field adjustable versions are available. Standard versions are supplied with brass pressure connections, Buna-N diaphragms for low pressure units or Buna-N O-rings in the high pressure sealed piston design, and 12″ wire leads. The rugged Maxtrol™ pressure switch is engineered for tough industrial use. For more information, contact Barksdale Controls Division, Imo Industries Inc., 3211 Fruitland Ave., Los Angeles, CA 90058, (213) 589-6181.

Barksdale Circle 512



Custom Length Capillaries

Externally adjustable temperature switches cover the −65° to +600°F working range. Single or dual setting models have watertight explosion-proof (NEMA 4,7,9) housings. Dial knobs calibrated in °F or °C are protected with separate tamper-proof covers. Removable front cover simplifies wiring to terminal boards. Stainless bulb and capillaries come in 6′ and 12′ standard lengths or to suit special requirements. Armor available. Mount in any position: not sensitive to motion or vibration. For additional information, contact Barksdale Controls Division, Imo Industries Inc., 3211 Fruitland Ave., Los Angeles, CA 90058, (213) 589-6181.

Barksdale Circle 513

All Solid-State, Ultra Stable

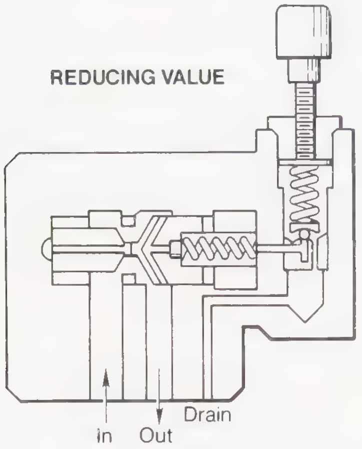
New inside and out, the 400 Series Transducer from Barksdale is a performance champ. Compare these features:

- Accuracy: ±0.25% Best Straight Line, including linearity, hysteresis and repeatability.
- Stability: Within ±0.5% of Full Scale Output over one year guaranteed. ±0.2% typical.
- Thermals: ±1.0% max. over 100°F compensated range (referenced to 75°F).
- Operating ranges of 0-15 to 0-7500 psi gauge and absolute.
- 300 series stainless steel wetted surfaces.

For full information, contact Barksdale Controls Division, Imo Industries Inc., 3211 Fruitland Ave., Los Angeles, CA 90058, (213) 589-6181.

Barksdale IMO

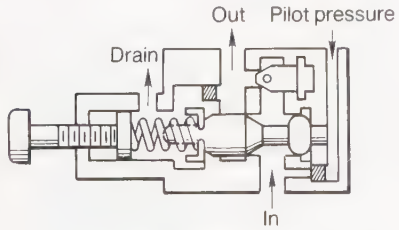
REDUCING VALUE



minimum pressure has been developed in one part of the circuit before fluid can pass through another part.

Reducing valves can limit pressure levels by restricting flow through a portion of a hydraulic system. In a normally open two-port unit, the reducing valve receives the signal from its low-pressure outlet. The valve is often biased by a spring or weight that may be supplemented with a pilot mechanism.

Reducing valves are used with suitable orifices to provide uniform pressure drop in flow-control valves. A check valve can be included for uncontrolled return flow through the valve, or pilot pressure can be used to hold the spool in the open positive to permit free return flow through the valve.



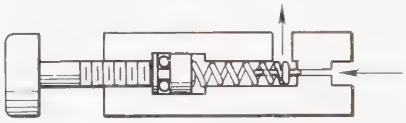
UNLOADING VALVE

Unloading valves provide free passage through a low-pressure area when a signal is applied to a pilot connection. In a typical application, unloading valves can be arranged to accept a signal from an accumulator. At a predetermined pressure, when the accumulator is charged to the specified level, the pump unloads to tank. The unloading pressure of this type of valve is commonly determined by a spring-loaded spool; the spring can be adjusted to vary unloading pressure. Alternatively, the valves can be controlled by application of a pilot pressure to hold the valve closed at pressures higher than that provided for by the spring.

Safety valves pop open to avoid or eliminate abnormally high pressure peaks. They are designed strictly for fast action rather than pressure modulation, and they may well be subject to such problems as noise and chatter. They are typically nonadjustable, or have the pressure setting protected from tampering.

Essentially, safety valves perform the function of "fuses" in the system. In lieu of one, devices called hydraulic fuses also can be used. These quasi-valves use a disc or similar device that fractures at a preset pressure. They do not reset automatically and must be manually repaired after fracturing.

Relief valves do the same job as safety valves, but they also smoothly and continuously modulate flow to keep pressure from exceeding a preset level. A relief valve is normally closed until the pressure level approaches a preset value. As system pressure rises, relief flow through a properly sized valve increases until the entire pump output passes through the valve. When system pressure drops, the valve closes smoothly and quietly.

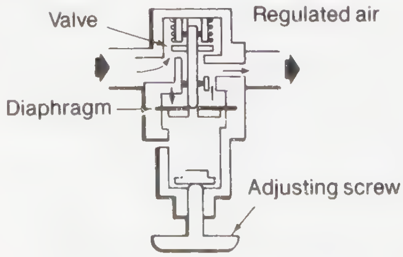


RELIEF VALVE

Relief valves are available with simple direct actuation or with piloted operation. In addition, some electrically modulated relief valves perform an almost servo function to instantly modulate system pressure over a wide range of electrically signaled values.

Pneumatic pressure regulators

Pressure regulators, commonly called pressure-reducing valves, maintain constant output pressure in compressed-air systems regardless of variations in input pressure or output flow. Regulators are a special class of valve containing integral loading, sensing, actuating, and control components. Available in many configurations, they can be broadly classified as general purpose, special purpose, or precision.

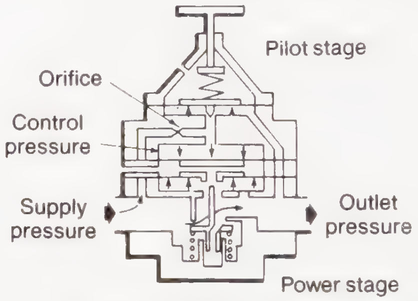


BASIC PRESSURE REGULATOR

General-purpose or utility regulators have flow and regulation characteristics that meet the requirements of most industrial compressed-air applications. Such regulators provide long service life and relative ease of maintenance at competitive prices.

Precision regulators are for applications where regulated pressure must be controlled with close tolerances. Such regulators are used when the outcome of a process or the results of a test depend on accurate pressure control.

Special-purpose regulators often have a unique configuration or special materials for use with fluids other than compressed air.



PILOT OPERATED REGULATOR

Regulator construction can range from simple to complex, depending on the intended application and the performance requirements. However, the principle of operation and the loading, actuating, and control components are basic to all designs.

Most regulators use simple wire coil springs to control the downstream pressure. Various size springs are used to permit regulation of the secondary pressure within specific ranges. Ideally, the required pressure should be in the center one-third of the rated outlet pressure range. At the lower end of the pressure range, the spring loses some sensitivity; at the high end, the spring nears its maximum capacity.

Regulators can use either a piston or diaphragm to sense downstream pressure. Diaphragms are generally more sensitive to pressure changes and react more quickly. They should be used where sensitive pressure settings are required (less than 0.04 psi). Pistons, on the other hand, are generally more rugged and provide a larger effective sensing area in a given size regulator.

The functional difference between precision and general-purpose regulators is the degree of control accuracy of the output pressure. Output pres-

Machine Design

reprints mean business.

Let us put them to work for you.

Reprints of your advertisements and "Machine Design" articles can be used as:

- ☞ *Direct mail to customers and prospects.*
- ☞ *Sales aids for your people in the field.*
- ☞ *Tools to inform stockholders and employees.*
- ☞ *Training aids for new employees.*
- ☞ *Handouts at trade shows and company meetings.*
- ☞ *New product announcements.*
- ☞ *Follow-ups to ad inquiries.*

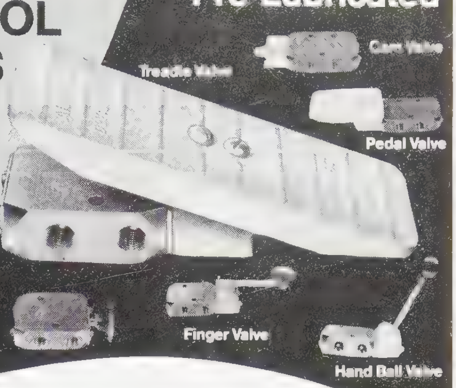
For more information about this cost-effective way to get your message out to your customers and staff or to place an order, call Linda L. Fouts, reprints manager, at (216) 696-7000.

MACHINE DESIGN is a publication of:
Penton Publishing
1100 Superior Avenue, Cleveland, Ohio 44114

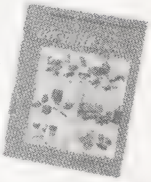
air-mite
CONTROL VALVES

Low Cost
Durable
Pre-Lubricated

Patented design permits millions of trouble-free actuations



- **Interchangeable actuators**
- **Low silhouette mounting**
- **2024 T4 aluminum bar stock**
- **Manual and Mechanical Actuation**
- **Full flow air passages**
- **Piped exhaust ports**
- **Anodized finish**



Available in 3, 4 and 5-way models for ⅛", ¼", ⅜", and ½" pipe sizes. "O" ring packing permits free ram movement, ensures long valve life. Port entry from either right or left side. Optional hand and foot guards are available.

Call 312 286-3393 or write for details and free catalog.

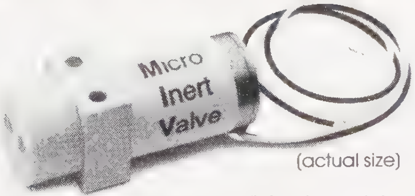
air-mite

AIR-MITE DEVICES, INC.
4739 West Montrose Avenue
Chicago, Illinois 60641

Circle 515

Flows both ways.

Flows both ways.



(actual size)

Our Micro Inert Valve (MIV) features bi-directional, clog-resistant flow in a chemically inert valve, so it can handle blood and cell growth media as well as hydrochloric acid. And that's just part of the story:

- ○ Chemically inert design
- ○ Lower power consumption – 750 mW at 12 vdc
- ○ Vacuum or pressure service
- ○ Small internal volume – to 4 μL
- ○ Zero dead volume
- ○ Complete flushability
- ○ MINSTAC Port or Manifold Mount versions

Call or write today for more information.

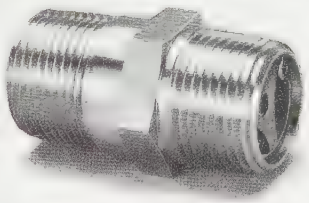
The Lee Company
2 Pettipaug Road
P.O. Box 424
Westbrook, CT 06498
Tel: (203) 399-6281
Fax: (203) 399-7037

Lee. Innovation in Miniature.

LEE

Circle 516

CHECK IT OUT!



2200 Series

Economical Check Valves

Quality precision check valves provide quick opening and positive closure at cracking pressures down to 0.5 psi. Resilient O-ring seal achieves bubble-tight shutoff and eliminates chatter. Compact, economical check valves in ⅛" to 1¼" sizes, for pressures to 800 psi, come in a choice of materials.

Precision Products
CIRCLE SEAL CONTROLS
Phone (714) 774-6110 ■ Fax (714) 772-7332

Circle 517

MOTORIZED PRESSURE CONTROL

While pressure regulators can be operated manually or with pneumatic signals, coupling pneumatic regulators with advanced electric drives offers some unique advantages, particularly in remote control or automated applications.

Operation of a motor-controlled pressure regulator is rather basic: The adjusting screw on a standard regulator is controlled by an electric actuating motor. Operating the motor turns the adjusting screw, which in turn changes the regulator set point and downstream pressure accordingly. The motor must be reversible because pressure must be both increased and decreased.

Three types of electric motors currently used on motor-controlled regulators are ac synchronous, dc, and dc stepping. Ac synchronous motors, which are controlled by an analog signal, are generally intended for "man in the loop" applications. Control is simple, requiring only a three-position switch. Any over or undershoot is manually compensated for.

Synchronous motors are less expensive than stepping motors, and generally run at lower speeds than the other types. They also have quick start and stop capabilities, resulting in little coasting or overrunning of pressure once power is shut off. Dc, on the other hand, normally run at high speeds and have high inertia armatures. Characteristically, they coast somewhat after power is removed.

The stepping-motor-controlled pressure regulator has the highest precision and is the most versatile of the group. It is also generally the most expensive. Because the motor is controlled by electrical pulses, digital control of air pressure is possible. The stepper motor can be used in manual control applications for ramping of air pressure. But it is primarily intended to be controlled by a computer.

Digital designs are unusual in that they generally are open-loop systems, yet provide excellent accuracy. Contrary to what is commonly accepted, a complicated feedback circuit is not necessary for precision control. Of course, the system must be designed with virtually no backlash or hysteresis by using hardened couplings and gearing.

The digital system works by matching a set number of electrical pulses, or steps, to a corresponding change in pressure. The computer monitors position, and need not refer to some reference location. In addition, the system can be programmed to compensate for nonlinearity in the regulator itself.

sure accuracy is determined by the droop due to flow changes (regulator characteristics).

Pressure droop is most pronounced when the valve first opens. Factors contributing to droop are: load change with spring extension, effective area change with diaphragm displacement, and unbalance of area forces on the valve. The amount that output pressure changes with variations in supply pressure is called the regulation characteristic and is influenced by the ratio of diaphragm area to valve area and the degree of valve unbalance.

When selecting a pressure regulator, the important factors to consider are:

1. Normal line pressure.
2. Minimum and maximum regulated pressure required: Regulators can have a broad adjustment range and may require a specific spring or accessory to match the requirements. Also, minimum and maximum pressure should be within the middle third of the regulator range.
3. Maximum flow required at regulated pressure.
4. Pipe size: Not all regulators are available in all pipe sizes; note where adapters are required. Also, pipe size should be consistent with flow requirements.
5. Regulator adjustment frequency: A number of different adjusting methods are possible. When selecting a regulator, consider the location, application, adjusting method, and user.
6. Degree of pressure precision required.
7. Accessories or options include gages and panel mounting.
8. Environmental or fluid conditions that could be incompatible with materials used in the regulator.
9. Special features such as high relief or remote control.
10. The consequences of a regulator malfunction or failure: A damper or relief valve might be needed to protect personnel or equipment.

Also, dead-end service or intermittent actuation may require positive valve shutoff, bleed units, or close control of pressure-relief points. Filters, lubricators, relief devices, and other system options should be considered in the selection process.

Proportional valves

The performance of proportional valves falls in the wide spectrum between on/off solenoid valves and electrohydraulic servovalves. The valves are termed proportional because output flow is not exactly linear in relation to input current. Despite their nonlinear response, the valves are an inexpensive way to control position, velocity, or force on equipment requiring high-speed response at high flow rates.

Many proportional valves are modified versions of four-way, on/off solenoid valves in which proportional solenoids replace conventional solenoids. In operation, solenoid force is balanced by spring force to position the spool in proportion to the input signal. Positioning accuracy can be improved by removing the centering springs and adding a positioning sensor to the end of the spool. The sensor signal then cancels the solenoid signal when the spool reaches the specified position.

Proportional valve parts are built to be interchangeable; thus, the spool in low-performance valves can have considerable overlap in the null position. This overlap causes flow deadband, which is not critical for flow-control systems but can cause errors and instability in positioning systems.

However, a definite trend in the valve industry is the increasing difficulty in differentiating between servo and proportional valves. Historically, proportional valves could not match servovalve performance and were primarily used in open-loop applications. They were mass produced, while servovalves required meticulous manufacturing and fit-up, making them up to ten times more expensive. Proportional valves also had wider clearances, making them more forgiving and more tolerant of contamination. However, such definitions no longer hold in many cases.

For example, closed-loop proportional valves are available that function much like servovalves. By using high-force, continuous-action solenoids, minimum-friction mechanical moving parts, and rapid-response electronics, the valves offer servolike performance without drawbacks like contamination sensitivity and high pressure drop. A key feature in the valve is a spool and sleeve assembly with no overlap in mid-position. While this requires precise manufacturing, it is less costly than other servo designs.

The valves control flow or pressure, or actuator position, velocity, force, or torque, and can synchronize the action of a number of cylinders. They are suited for applications such as press systems and molding machines, for traditional servo markets like flight simulators and airframe testing, and for those areas currently using proportional systems that need to further upgrade performance with a closed-loop system.

Some manufacturers are producing proportional valves that are essentially servovalves made to mass-production specifications, with much greater tolerance allowances and looser fits than in their standard servo line. However, adding electronic feedback results in performance almost as good as that of a servovalve. In many cases, this gives performance perfectly suited to an application at a lower cost.

PROPORTIONAL PNEUMATICS

Until recently, pneumatic systems were almost entirely limited to on/off control — for example, pressure applied or not applied, or a cylinder extended or retracted. However, advances in closed-loop control theory, development of fast-acting precision pneumatic valves, and the availability of high-speed electronics and user-friendly interfaces now make proportional pneumatics a reality, offering performance that matches that of closed-loop electrical and hydraulic systems.

Closed-loop pneumatic control systems contain several components. A positioning drive, for example, consists of a continuous-acting valve as the control element; the cylinder and load as the controlled elements; feedback sensor or displacement pickup; control board and electronic controller; and an electronic amplifier that adjusts controller power level to that of the valve.

As the control element, the valve plays a key role in the control loop. Valve speed determines how rapidly the system compensates for unwanted deviations. A rule of thumb that governs the stability of closed-loop control requires the valve natural frequency to be at least three times that of the controlled system (for example, the cylinder and load to be moved).

In hydraulic servosystems, air entrapped in the hydraulic fluid increases fluid compressibility, leading to control difficulties. Obviously, with pneumatics, compressibility presents a much greater problem. Overcoming it is the key to pneumatic closed-loop circuit theory. If differs from other closed-loop systems in that control does not depend solely on proportional feedback — a number of other variables come into play as well.

The result is a complex, completely nonlinear closed-loop system, where computational constants must be corrected for stroke, pressure, and load. A large number of calculations, thus, are necessary, requiring a powerful microprocessor — faster than those found in hydraulic servosystems.

Positioning capabilities of 0.01 mm (0.0004 in.) are possible with a control valve and a digital controller. Realistically, however, implementation difficulties and costs increase dramatically as accuracy increases, regardless of the system used. Currently, the major benefit of proportional pneumatics is not so much high accuracy or high speed, but rather free programmability. Today, numerous applications require accuracy in the 1 to 0.1-mm range and are prime candidates for pneumatic closed-loop control. In these cases, there is no need for costly digital controllers.

Servovalves

Electrohydraulic servovalves, capable of controlling pressure, flow, or position in proportion to an electrical input, offer unsurpassed performance in a fluid-power system. At one time, conventional servovalves used on aircraft or machine tools provided operating characteristics exceeding those required for industrial and mobile applications. They were also too expensive and too sensitive to environmental contamination.

However, with the development of custom designs specifically for industrial and mobile equipment, the use of servovalves is moving into the critical circuits of these systems. For example, most robotic applications involve relatively low hydraulic resonance, in the range of 3 to 5 Hz. This low resonance is a result of the high load masses and large fluid volumes under compression in a typical robotic system. Also, the typical flow range for these systems is 10 to 40 gpm. Conventional servovalves supplying this level of flow have frequency response capabilities of 120 to 130 Hz at 90° phase lag, far higher than is required.

The valves can be modified to trade frequency response for increased spool operating force by enlarging the spool area exposed to pilot pressure. Increasing this area by 2 to 2.5 times, for instance, increases spool actuating force by an equivalent amount while lowering frequency response to 20 to 80 Hz at 90° phase lag. Higher spool actuating force enables the valve to overcome spool seizure caused by silting, thus improving system reliability.

Servovalves were adapted to the mobile market primarily by opening critical clearances in the pilot stage, making them more compatible with practical filtration levels. The wider clearances, and the use of hardened materials, allows contaminants to simply wash through the valves without clogging or causing damage.

Today, the use of servohydraulics usually is justified when one or more of the following characteristics is required: high load stiffness (both static and dynamic), good stability, precise positioning, good velocity and acceleration control, good damping characteristics, and predictable dynamic response.

In a servovalve, a given electrical signal produces a definite position of the main-stage spool, but it does not necessarily produce a fixed flow. Flow is a function of the square root of the difference between supply pressure and load pressure. Thus, as load pressure increases, both flow and effective pressure drop across the valve decrease.

Gain-compensated valves incorporate internal feedback to correct for load-fluctuation effects on output and, thus, more nearly approach the ideal steady-state curve. Amount of correction depends on the valve design. Where high accuracy is needed for either velocity or position, experts recommend an external transducer and feedback loop.

Steady-state characteristics are used to specify valve operating properties to ensure that the required system operating characteristics are not compromised by a limiting action of the valve due to inadequate flow, pressure, or input current; excessive null shifts; or other foreseeable causes. However, some of the steady-state valve parameters must be based on dynamic analyses to ensure required system response.

Flow: A flow curve is obtained by cycling the valve over the rated input current range and recording a continuous plot of output flow vs. input current for one cycle. It is used to measure valve flow gain, hysteresis, linearity, and symmetry.

Generally, the flow curve forms a closed loop. The locus of the midpoints of this loop is the zero-hysteresis flow curve; portions corresponding to the two polarities may differ (symmetry). The flow curve is generally divided into three operating ranges — null region with low input currents, region of normal flow control at intermediate input currents, and the flow-saturation region near rated input current.

Flow gain is change in output flow per unit change in input current, under zero load unless otherwise specified. Therefore, the slope of the normal flow curve in any specified region is the flow gain. When the term flow gain is used without reference to a particular region, normal flow gain is implied. Ideally, rated flow gain would be equal to normal flow gain, which is the slope of a straight line drawn from the zero flow point to equalize deviations of the flow curve from a straight line.

Pressure characteristics: Pressure gain is related to the rate of pressure increase per unit current increase. Pressure gain characteristics are very important because in a practical system some usually small, but finite, value of output-pressure change is required to overcome load friction before load movement is possible. Thus, the entire system is affected by the pressure-gain characteristics of the valve.

Null characteristics: Ideally, a valve produces zero output at zero current input. In practice, this ideal condition is seldom attained. The null shift may be due to changes in temperature, supply pressure, and return or load pressure. It is expressed in terms of null bias, or the current change required to produce zero flow.

Dynamic characteristics have an important effect on the dynamics of the system. The transient response of the valve can be so slow that it limits the transient behavior of the entire system. An inherent resonance can cause system instability or oscillation. Limits for the dynamic characteristics of each component must be specified if the required system dynamics are to be maintained. Valve dynamics can be determined either by a transient-response or a frequency-response test, depending on the specific system application. ■

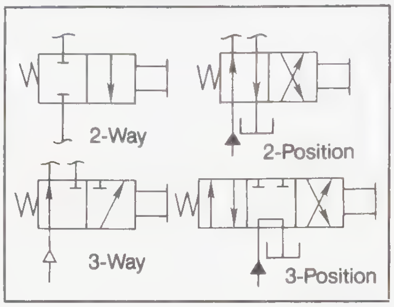
PORTS AND POSITIONS

Porting determines the ways that flow can be directed through a valve. For either hydraulic or pneumatic direction-control valves, porting is determined to ensure that fluid can be presented to the right side of the right actuator at the right time.

Port number of a valve is the number of valve ports the valve can pressurize or exhaust. Thus, a three-port valve that can handle one actuator port would be a three-way valve, and a four-port valve able to pressurize two ports would be a four-way valve.

Valve positions are determined by the number of stops the valve "internals" can make during operation. A two-position valve can shift either one way or the other, like a two-position toggle light switch. Three-position valves, of course, have an intermediate position between the two end stops.

Most manually operated valves with modulating capabilities — such as slide or rotary valves — can be considered as either two or three-position valves, with some capability of stopping between positions. Most poppet valves are two-position units; and spool valves are typically either two or three-position valves. A few valves have more than three positions to provide auxiliary functions, such as porting to a feed-control line.



Experts agree that a three-position valve is the most versatile. It can hold an actuator in an intermediate position, provide a path for fluid back to the tank while the actuator is still, and isolate an actuator from the rest of the circuit.

From Start To Finish

MICO Hydraulic Accumulator Charging Valves

- Use power developed in the main hydraulic circuit of mobile equipment with varying pump flows
- Remote mounting from brake valves and snap action control for positive unloading of the pump
- Settings are adjusted at the time of manufacture to conform to specific customer requirements
- Available in single, dual, and load-sensing configurations
- System pressures to 3000 psi; flow through capacity, 2-30 gpm; flow through pressure drop, 70 psi at 15 gpm; max upper accumulator pressure limit, 2750 psi

MICO Pedal-Actuated Power Brake Valves

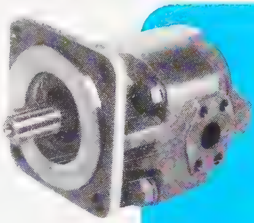
- Closed center design used for modulating output pressures up to 3000 psi
- Provides normal and emergency power-off braking when used with a properly sized accumulator
- Spool-type construction provides smooth modulation at low pressures
- Direct acting spool provides a pedal feel accurately representing brake pressure
- Various reaction areas in combination with several optional pedal ratios provide pedal force requirements for different brake systems

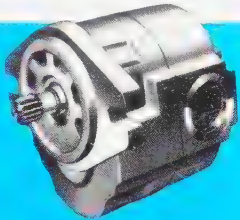
MICO 1911 Lee Blvd., N. Mankato, MN 56003, Fax: (507) 625-3212 / Phone: (507) 625-6426

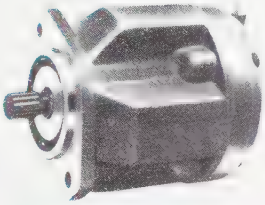
Circle 518

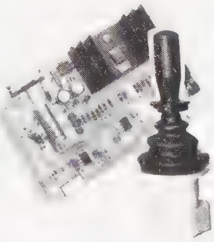
REXROTH

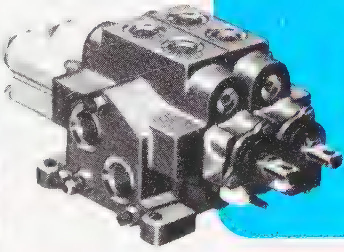
The Rexroth Mobile Hydraulics Division supplies the mobile equipment market with a full line of hydraulic components, hydrostatic transmissions and accessories.











- agricultural valves
- brake valves
- bent-axis motors
- bent-axis pumps
- custom-built valves
- check valves
- constant torque control
- crane and winch controls
- cartridge valves
- counterbalance valves
- closed center valves
- directional control valves
- electric proportional valves
- electric proportional controls
- electronic servo controls
- fixed displacement piston motors
- fixed displacement piston pumps
- flow control valves
- flow divider/combiner valves
- gear pumps
- gear motors
- gearboxes
- high pressure monoblock valves
- hydrostatic transmissions
- hydraulic power brake valves
- hydraulic pilot controls
- horsepower limiting controls
- hydraulic winches
- hose break protection for cylinders
- low-speed high-torque motors
- load-sensing valves
- load-sensing pumps
- manual controls
- open center valves
- power steering pumps
- pressure compensating valves
- pressure switches
- PTO pumps
- pressure sequence valves
- pressure reducing valves
- rotary joints
- regenerative valves
- stack valves
- swing gearboxes
- speed-sensing controls
- swing controls
- swashplate motors
- swashplate pumps
- shuttle valves
- track drive gearboxes
- track drive controls
- tandem pumps
- variable displacement piston motors
- variable displacement piston pumps
- wheel drive gearboxes
- winch drive gearboxes

Rexroth's full line of products have consistently met the rigorous design and performance specifications of mobile original equipment manufacturers. Rexroth mobile hydraulic equipment can be found in dozens of heavy-duty applications — working, enduring, supplying optimum operational efficiency. As a leader in the hydraulic industry, Rexroth supplies and services the mobile equipment market on a worldwide basis in more than 40 countries with 30,000 different product designs.

The Rexroth Corporation
Mobile Hydraulics Division
1700 Old Mansfield Road,
P.O. Box 394
Wooster, OH 44691-0394
1-800-922-0688 Ext. 1535

REXROTH
WORLDWIDE HYDRAULICS

In Canada call Basic Hydraulic & Industrial Equipment, Ltd., (416) 735-0510

Hydraulics on the move!

Power actuators, motors, and shock absorbers

Actuators convert fluid energy into useful work.

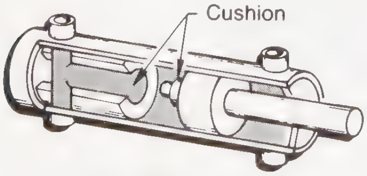
Fluid-power actuators are available in a number of forms to provide specific types of action. Cylinders work through linear extension; motors impart continuous rotary motion to objects; rotary actuators twist an object through only a partial arc.

Generally, all types of actuators are available for pneumatic or hydraulic operation. Often, the same cylinder can be used for either air or low-pressure oil operation. Air and hydraulic motors, though similar, are usually not interchangeable.

Cylinders

When fluid is pumped into a cylinder, piston and rod are forced to move in or out against a load. Movement can be all at once, or in increments; the piston may even rotate or carry fluid. It can be returned by gravity, springs, or reversed flow.

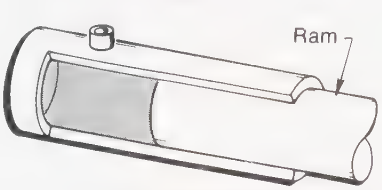
Single-acting cylinders, the simplest type, power a stroke in only one direction. When the fluid is allowed to drain from the cylinder, some external force must push the piston back to its starting position. This low-cost cylinder can be used for any job — like a lift against gravity — that provides a returning force.



CUSHIONED CYLINDER

Cushioned cylinders are single-acting cylinders with a built-in shock absorber. Where the function of the cushion is to reduce shock or hammering against the cylinder head, cushions are usually nonadjustable. But adjustable cushions are available for applications where precise cylinder speed is important.

Ram cylinders are usually single-acting types with a rod at or near full-piston diameter. The large-diameter ram is favored when column loads are extremely high or when the rod overhang in a horizontal cylinder could cause sagging. Ram cylinders are frequently used for large press applications and for jacking.

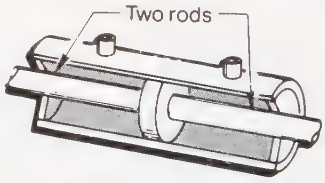


RAM CYLINDER

Spring-return cylinders are similar to the low-cost single-acting types, but with a spring added to return the piston to its starting point. This type is widely used in both pneumatic and hydraulic service, but is not always suitable for hydraulic service; if the spring is heavy enough for speedy piston return, it may require too much force to compress. The cylinder must be about twice as long as the required stroke to include space for the spring. Some cylinders are spring loaded in the opposite direction, so they extend with spring action and retract pneumatically or hydraulically.

Double-acting cylinders contain two fluid chambers so that pressure can be used to both extend and retract the rod. Sealing devices work in both directions. This type of cylinder is by far the most common, and can be used in nearly all types of applications. Effective working area of the rod side of the piston is less than that of the other side, so double-acting cylinders retract faster than they extend, and exert less force on the retraction stroke.

Double-end rod cylinders are double-acting types with a rod extending from each side of the piston. A chief



DOUBLE-END ROD CYLINDER

SIZING CYLINDERS

Cylinders may be the most overspecified component in the average fluid-power system. An oversize cylinder has a healthy extra margin of force that can override a bit of misalignment, binding, or overload. However, extra cylinder size can also boost cost, increase weight, and retard actuation.

Piston size is determined by required force F and available pressure P in the relationship $F = PA$. Piston diameter can be found from area A. For example, if a 10,000-lb force must be exerted by a 1,000-psi system, minimum piston area of 10 sq in. must be provided.

Speed of a piston is determined jointly by its size and the flow volume into the cylinder. As the piston is displaced, the volume swept must be fully replaced with fluid.

Rod size must be large enough to withstand the stresses imposed by load and cylinder. For pure tension applications, size determination is simple: Rod area is found by dividing piston force by rod yield strength and applying a safety factor.

Calculations for compression (thrust) applications are much more complicated. In compression, the rod acts like a slender column, and must be of adequate strength to prevent buckling. The extra strength required depends on the stroke length and connection between rod and cylinder.

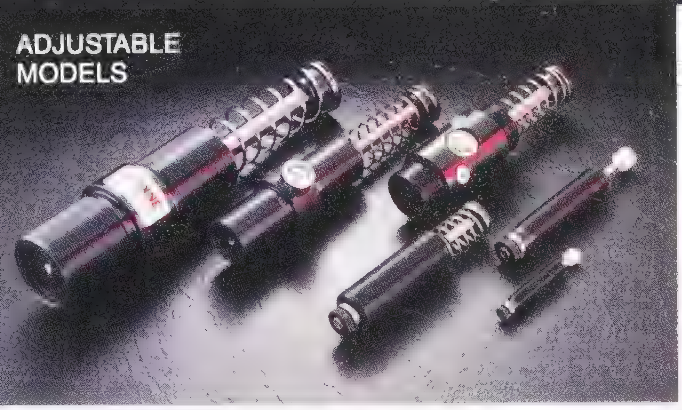
For longer strokes, a stop tube may be required. Such a tube fits inside the cylinder, in front of the piston, and stops the piston before the end of its stroke. Thus, the tube acts as a spacer to keep the two cylinder bearing areas (rod and piston) separated and to keep buckling resistance high.

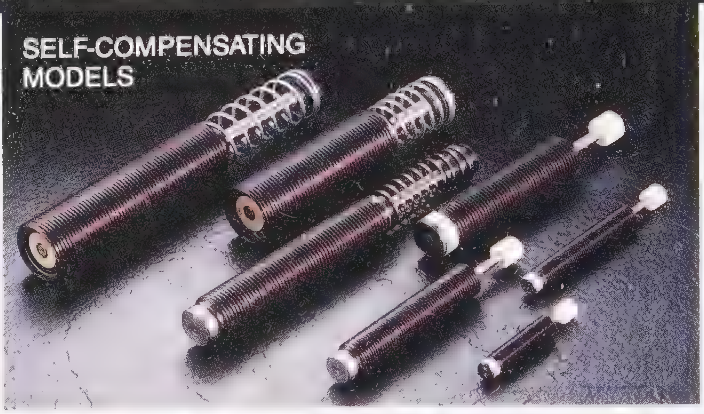
WHERE DO THE BEST IDEAS IN ENERGY ABSORPTION COME FROM

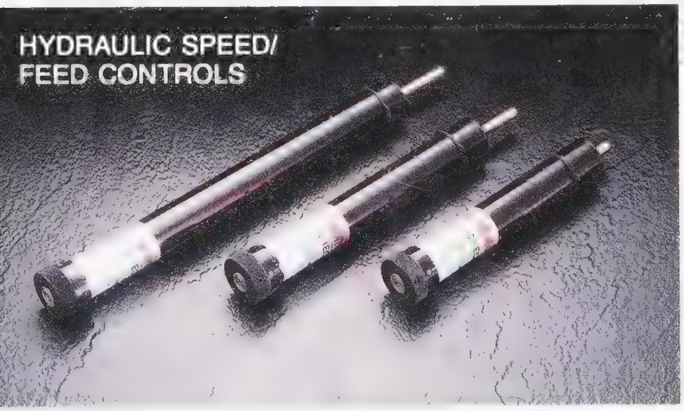
?

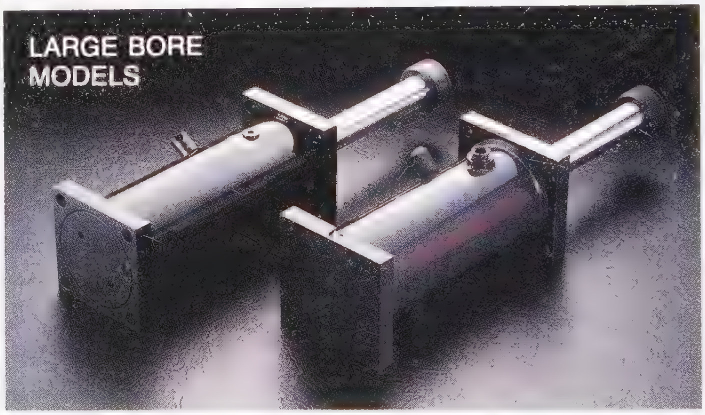
Circle 519

ENIDINE IS


ADJUSTABLE MODELS


SELF-COMPENSATING MODELS

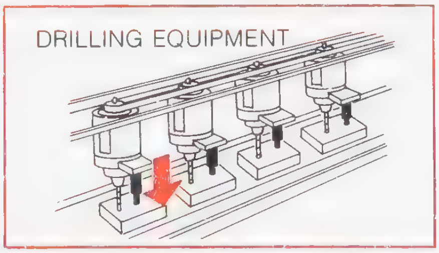

HYDRAULIC SPEED/ FEED CONTROLS

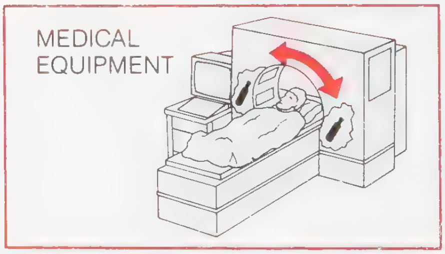

LARGE BORE MODELS

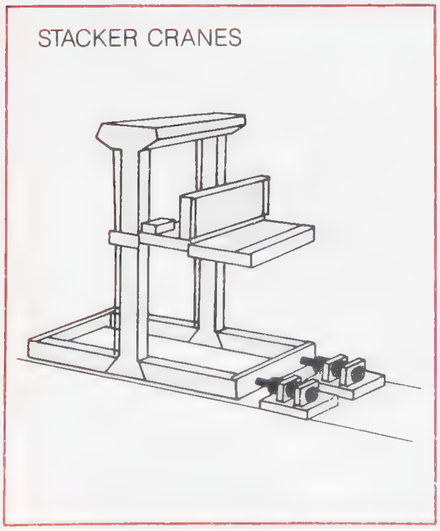
SHOCK ABSORBERS

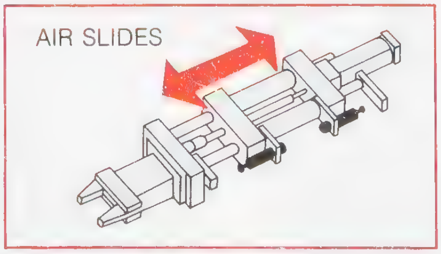
ENICOTE
PROTECTION

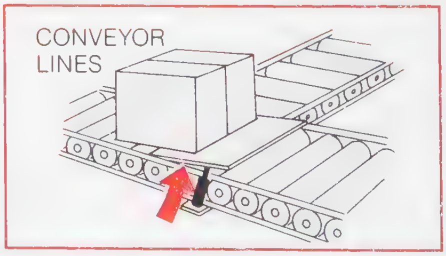
- Provide shock absorption and speed/feed control
- Highest quality, widest variety
- Standard and custom designs
- Satisfy industrial and aerospace applications

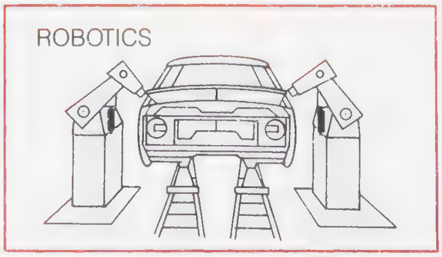

DRILLING EQUIPMENT

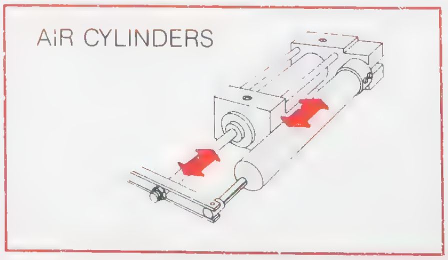

MEDICAL EQUIPMENT


STACKER CRANES


AIR SLIDES


CONVEYOR LINES


ROBOTICS


AIR CYLINDERS

YOUR ANSWER.

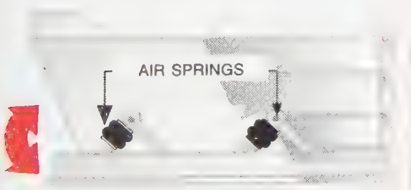
AIR SPRINGS

- Dual vibration isolation and actuation capabilities
- Highly durable, cost effective
- Outperform coil springs and air cylinders

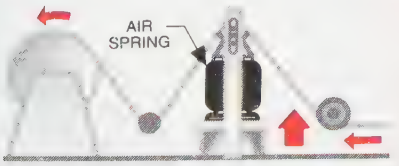
WIRE ROPE ISOLATORS

- Protection against shock and vibration
- Superior multi-axis isolation
- Long life, high reliability
- Patented construction

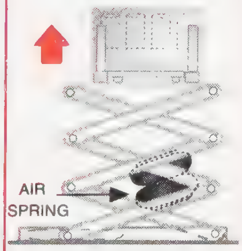
VIBRATING SCREENS



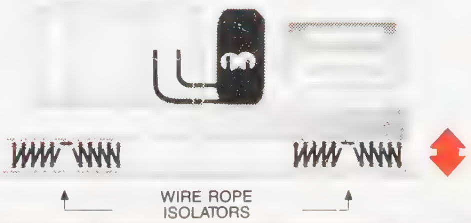
TENSIONING MACHINERY



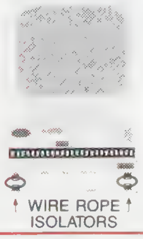
SCISSOR LIFTS



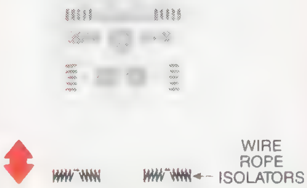
ROTARY EQUIPMENT



COMPUTERS



ELECTRONICS



Circle 519

ENIDINE

7 Centre Drive
Orchard Park, New York 14127
TEL: 716/662-1900 • FAX: 716/662-1909 • TECHNICAL HOTLINE: 800/852-8508

SUBSIDIARIES AND AFFILIATES

Enidine West
212 Technology Dr., Suite M
Irvine, California 92718 • USA
TEL: 714/727-9112
FAX: 714/727-9107

Enidine S.A.
17-19, rue Fernand Drouilly
92250 La Garenne Colombes
FRANCE
TEL: 33 1 42421144
FAX: 33 1 42421116

Enidine GmbH
Luetemannsweg 1 • Postfach 1170
D-7858 Weil am Rhein 5
GERMANY
TEL: 49 7621 6741
FAX: 49 7621 63966
TELEX: 773 959

Enidine Co. Ltd.
Hongo 3-13-1 (Abe Bldg)
Bunkyo-Ku, Tokyo • JAPAN
TEL: 81 33 8161761
FAX: 81 33 8161744

Enidine Corporativo De Mexico, S.A. de C.V.
Compostela 1806
Mezquitan Country
Guadalajara 44290, Jalisco
MEXICO
TEL: 52 36 532825
FAX: 52 36 236365

Enidine Nederland B.V.
P.O. Box 540 • 2130 AM Hoofddorp
NETHERLANDS
TEL: 31 2503 39224
FAX: 31 2503 38730

Enidine Steelpaw A.S.
P.O. Box 43
N-3185 Skoppum • NORWAY
TEL: 47 33 70390
FAX: 47 33 70190

Enidine S.A.
Hurtado De Amezaga 27-5
48008 Bilbao • SPAIN
TEL: 34 4 4436388
FAX: 34 4 4449922

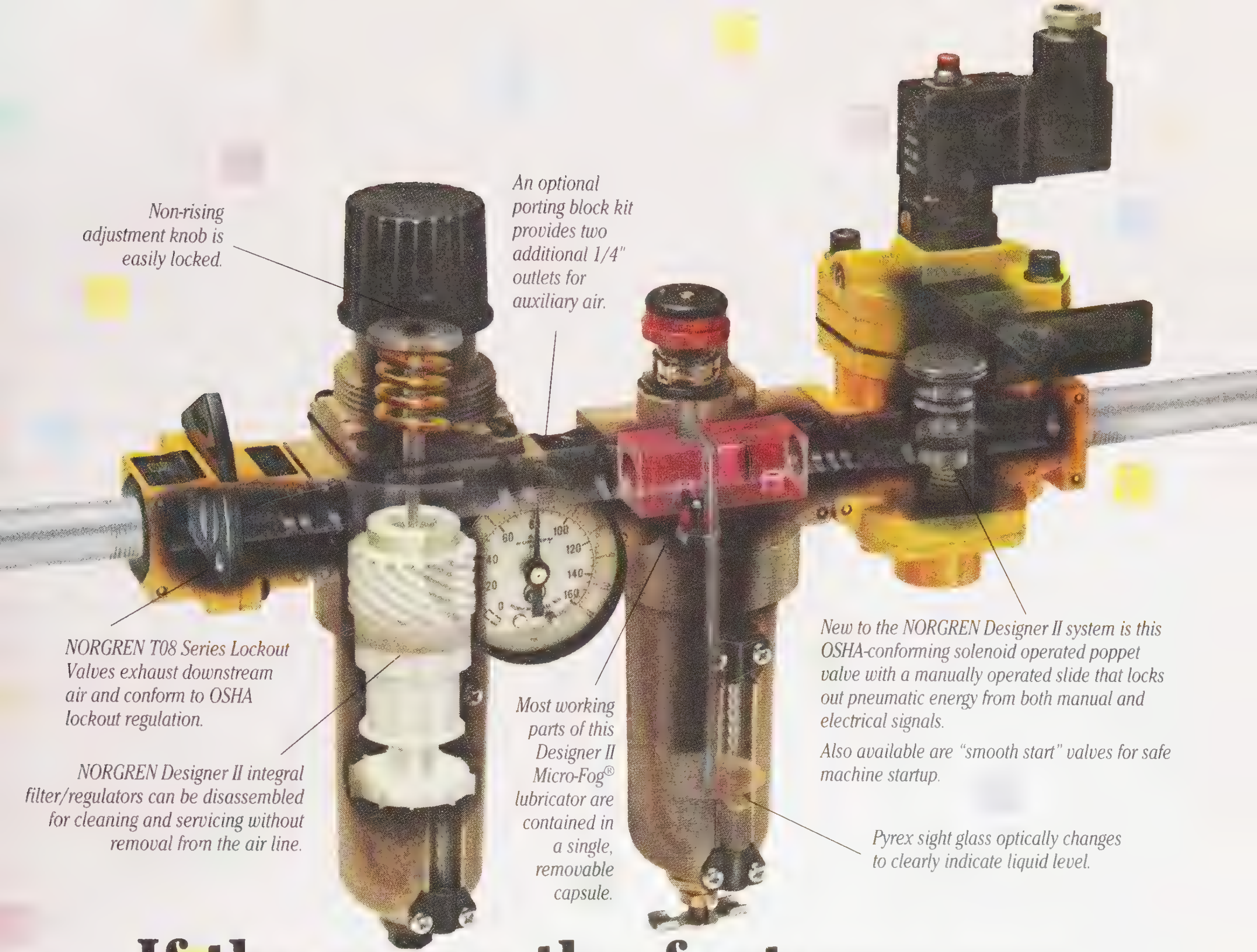
CREDIMEX AG • Enidine Division
CH-6060 Sarnen • SWITZERLAND
TEL: 41 41 663330
FAX: 41 41 668530

Enidine U.K. Ltd.
Unit C12, Holly Farm Business Park, Honiley • Kenilworth
Warwickshire CV8 1JB • UNITED KINGDOM
TEL: 44 926 484111 • FAX: 44 926 484040

NORTH AMERICAN DISTRIBUTORS

DISTRIBUTOR	PHONE	LOCATION
Control & Power, Inc.	205/870-0274	Birmingham, AL
Control & Power, Inc.	205/461-7398	Madison, AL
Wistech Controls Company	602/243-4361	Phoenix, AZ
Wistech Controls Company	602/790-9803	Tucson, AZ
Christenson-Bellows Valvair Ltd.	604/522-3761	Coquitlam, BC
Elect Air	714/984-9401	Ontario, CA
Elect Air	408/262-2252	Milpitas, CA
Numatic Engineering	213/666-5050	Los Angeles, CA
Fiero Fluid Power	303/373-2600	Denver, CO
Pneumatic Supply Inc.	813/539-6500	Clearwater, FL
Fluid Power South	404/455-8719	Chamblee, GA
Kiser Controls Company	708/920-9171	Burr Ridge, IL
Mosier Fluid Power of Indiana	317/356-5595	Indianapolis, IN
Skarda Equipment Co.	913/631-7001	Edwardsville, KS
Skarda Equipment Co.	316/265-1329	Wichita, KS
Mosier Fluid Power of Kentucky	502/499-8900	Jeffersontown, KY
Fluid Power Products	606/987-5512	Paris, KY
Fluid Power Products	812/479-3165	Evansville, KY
Fluid Power Products	606/231-8882	Lexington, KY
Fluid Power Products	502/451-9630	Louisville, KY
Air Incorporated	508/528-3020	Franklin, MA
J.S. Brayan Inc.	313/695-5090	Grand Blanc, MI
Automation, Inc.	612/571-3336	Minneapolis, MN
Frank Flori Equipment Company	314/432-3393	St. Louis, MO
Control & Power, Inc.	601/352-8909	Jackson, MS
Scott Equipment Company, Inc.	704/875-1611	Huntersville, NC
Skarda Equipment Company	402/422-0430	Omaha, NE
Air Powered Equipment	201/933-4777	Carlstadt, NJ
Wistech Controls Company	505/883-2552	Albuquerque, NM
Wistech Controls Company	702/387-7887	Las Vegas, NV
Hughes Industrial Products	716/759-8374	Clarence, NY
Hughes Industrial Products	518/869-6143	Albany, NY
Hughes Industrial Products	315/437-5730	Syracuse, NY
Hughes Industrial Products	716/654-6320	Rochester, NY
Hughes Industrial Products	607/770-0999	Johnson City, NY
Wyatt Sales	216/572-4888	Strongsville, OH
Mosier Fluid Power of Ohio	513/298-9846	Dayton, OH
Southwestern Controls	918/663-6777	Tulsa, OK
Buchanan Air	503/226-7868	Portland, OR
D & D Industries	416/745-4739	Woodbridge, Ontario
Hughes Industrial Products	814/833-2693	Erie, PA
Allegheny Fluid Power	412/367-5894	Pittsburgh, PA
Konstance Co., Inc.	215/430-1225	West Chester, PA
Pneumac Fluid Power, Inc.	514/745-1987	Montreal, Quebec
Air & Hydraulic Equipment Co., Inc.	615/943-1294	Nashville, TN
Air & Hydraulic Equipment Co., Inc.	615/558-9090	Knoxville, TN
Air & Hydraulic Equipment Co., Inc.	615/968-7044	Bristol, TN
Air Draulics Engineering Co.	901/794-4300	Memphis, TN
Air & Hydraulic Equipment Co., Inc.	615/528-1012	Cookeville, TN
Air & Hydraulic Equipment Co., Inc.	615/629-2571	Chattanooga, TN
Southwestern Controls	713/777-2626	Houston, TX
Southwestern Controls	214/638-4266	Dallas, TX
Southwestern Controls	512/522-1233	San Antonio, TX
Wistech Controls Company	915/532-9207	El Paso, TX
Fiero Fluid Power	801/467-4622	Salt Lake City, UT
Alt Controls	804/798-1489	Ashland, VA
Buchanan Air	206/282-4551	Seattle, WA
Buchanan Air	509/838-2117	Spokane, WA
Fluid System Components, Inc.	414/546-1502	Milwaukee, WI
Fluid System Components, Inc.	414/337-0234	Green Bay, WI
Fluid System Components, Inc.	414/921-7221	Fond du Lac, WI
Fluid Power Products	304/522-4067	Huntington, WV
Mosier Fluid Power of Ohio	304/744-5356	South Charleston, WV

Circle 519



Non-rising adjustment knob is easily locked.

An optional porting block kit provides two additional 1/4" outlets for auxiliary air.

NORGREN T08 Series Lockout Valves exhaust downstream air and conform to OSHA lockout regulation.

NORGREN Designer II integral filter/regulators can be disassembled for cleaning and servicing without removal from the air line.

Most working parts of this Designer II Micro-Fog® lubricator are contained in a single, removable capsule.

New to the NORGREN Designer II system is this OSHA-conforming solenoid operated poppet valve with a manually operated slide that locks out pneumatic energy from both manual and electrical signals.

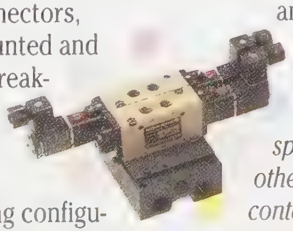
Also available are "smooth start" valves for safe machine startup.

Pyrex sight glass optically changes to clearly indicate liquid level.

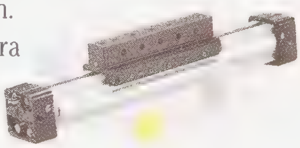
If these are the features you look for in a pneumatic system, look into NORGREN.

A salient fact that sets NORGREN apart from other pneumatic component suppliers is this: *Listening, and listening well, to our customers, our market, and individuals like you, remains the foundation of NORGREN's leadership role in the compressed air business.*

Consider, for example, the versatility of NORGREN's Designer II FRL system shown above. These units can be applied individually or assembled into a modular combination. When installed with modular connectors, they can be rail or wall mounted and serviced without tools or breaking pipe connections.



NORGREN's new Nugget family of air valves offers a variety of common mounting configurations for maximum flexibility and adaptability. Equally significant are the common operators, options, accessories and, most importantly, the internal design.



NORGREN Lintra rodless air cylinders require up to 50% less space than conventional cylinders yet provide equivalent thrusts and strokes. Lintra's distinctive, integral load guide system also allows the cylinder to withstand high axial and radial loads without using external guides or supports.

For complete facts and specifications on these and other NORGREN products, contact us at the address or toll-free phone number at the right.

NEW!

TECHNICAL SERVICE DIRECT FAX (303) 795-9487

For fast, accurate response, FAX us your name, phone and the nature of your inquiry.

NORGREN®
THE WORLDWIDE GOLD STANDARD IN PNEUMATIC PRODUCTS.

5400 South Delaware Street
Littleton, CO 80120 • (303) 794-2611
For the name of the NORGREN distributor nearest you, call toll free 1-800-766-6674.

Circle 520

RODLESS CYLINDERS

Rodless cylinders, as the name implies, differ from their more conventional counterparts in that no piston rod extends from the cylinder body. Rather, an internal piston is connected by some means to an external carriage. Driving the piston by compressed air or other suitable media causes the carriage to traverse between the cylinder end caps.

Thus, a major advantage of rodless cylinders is that they require considerably less mounting space — nearly 50% less in some applications. For this reason, rodless cylinders are generally specified where space considerations restrict the use of other options. Another area where rodless cylinders excel is in long-stroke applications. By design, rodless cylinders are unaffected by problems such as rod overhang and bending, piston cocking, and uneven seal wear, and they do not require external guides or rod supports.

Rodless cylinders are also replacing stepping motors and ball screw drives in a number of installations because they carry larger loads at higher velocities, yet are capable of precise positioning.

Cable cylinders were the first pneumatic rodless cylinders. In this design, rigid cables are attached to both ends of a piston. The cables pass through seals at the ends of the cylinder tube, around pulleys, and are joined at a carrier bracket. Air or hydraulic pressure drives the piston, causing carrier movement.

Cable cylinders are typically the lowest priced rodless linear drives, usually 30 to 50% less than a comparable band cylinder. However, cable cylinders also have a number of drawbacks. One is that cables, by their nature, are difficult to seal. Some manufacturers have attacked this problem by enclosing the cable in materials such as nylon. Cables are also prone to stretching in use, due to cable set, with individual wire strands bedding into one another. Some manufacturers overcome this problem by pretensioning cables before assembly into a cylinder, and through the use of manual or automatic tensioning devices attached to the cylinder. A somewhat more subjective complaint is that they do not have the sleek, streamlined look of band and enclosed-cable cylinders. Finally, cable cylinders can handle only longitudinal loads. Direct, radial loading, or bending moments, cannot be carried. However, some alternative designs have been developed to overcome this shortcoming.

Guided-cable cylinders are basic cable cylinders, except the carriage is supported by linear bearings which ride on hardened steel shafts. This permits support of axial and side loads. While more expensive than basic cable cylinders, they often cost less than band-type cylinders. Guided-cable cylinders generally cannot handle as high a load as can other cylinders, and bearing surfaces are exposed to the surroundings and possible prone to premature wear from dirt and grit.

Enclosed-cable cylinders operate on the same basic principle as do cable cylinders, except the entire unit is enclosed, and the carriage rides on either the tube exterior or an internal bearing surface. Advantages include high load-carrying capability and better protection for the cable seals. However, costs can be substantially higher than basic cable cylinders.

Slotted-tube have a slot that runs the length of the tube and is generally made from an aluminum extrusion. This allows the internal piston to be connected to an external carriage. The slot holds dynamic seals on both the inner and outer surfaces. The former acts as a pressure seal; the latter as an exclusion device. Carriage travel moves the seals out of the slot, and guides reposition the seals after the carriage has passed. While basic operation of various units is the same, there are substantial differences in sealing methods, carriage supports, and load-carrying capabilities from one manufacturer to another.

The cylinders are noted for their streamlined design, and are more compact than other band and cable cylinders. However, the dynamic seal that runs the length of the cylinder body poses a potential leakage source — particularly if dirt or grit passes the outer exclusion seal. Some critics also note that a slotted extrusion inherently is capable of carrying less load without deformation than can a totally enclosed tube.

Dual-chamber band cylinders operate in a similar fashion to enclosed cable cylinders, except that a high-strength steel band replaces the cable. Reportedly, a band is easier to wipe clean and seal than a cable, and it exhibits less stretch under load. Compared to slotted-tube cylinders, there are no dynamic seals running the length of the body. Thus, they experience less leakage and are less affected by dust and dirt. However, the dual-chamber design requires a larger cross-sectional profile than do slotted-tube cylinders.

Magnetically coupled rodless cylinders differ from other designs in that there are no exposed dynamic seals. Rather, the piston is magnetically coupled to the external yoke, which travels on the tube exterior. An advantage of this method is that only static seals are required at tube ends, and they are not prone to wear or affected by harsh operating conditions. Thus, there is no air leakage, which offers potential energy savings and is advantageous in clean-room, food-processing, and other such applications.

Critics of this approach note that there is no positive coupling between piston and yoke, thus limiting loads and velocities. Others note a potential safety hazard should external means cause yoke breakaway. Also, the magnets can attract metallic particles to the tube exterior, promoting surface wear. However, the same holds with magnetically attached seals found on some band cylinders, and whenever reed switches are used.

Some similarities hold regardless of the rodless cylinder design. For example, most manufacturers offer end-of-stroke cushioning — to decelerate the carriage and prevent shock loads — although cushion designs differ somewhat from one manufacturer to another. Position sensing through reed or Hall-effect switches, allowing control via PLCs or similar devices, is another common option. Load capacity of rodless cylinders decreases as the unsupported cylinder length increases. For this reason, midposition tube supports are commonly available. Finally, while these devices are typically prelubricated, operating on filtered and lubricated air is recommended.

Air-spring actuators, while not considered to be classic rodless cylinders, are rubber/fabric bellows that support and contain a column of compressed air. Unlike conventional pneumatic cylinders, the springs have no pistons, rods, or dynamic seals.

The rubber bellows is attached to upper and lower metal end plates, permanently sealing the device. Different metal-to-rubber closure options are available, including crimped and bolted styles, to suit particular needs. Standard two-ply actuators are rated for use at 100 psi. Higher-strength constructions are rated to 175 psi.

SUSPA
COMPART

SUSPA

Gas Cylinders

TYPE 16

SUSPA GAS CYLINDERS...FOR LIFTING, DAMPING AND COUNTER-BALANCING

Suspa gas cylinders offer a unique alternative to conventional mechanical or coil spring lifting or counterbalancing devices. The relatively flat force curve, controlled forces and extension speed, combined with damping at the end of the stroke, are characteristic of the advantages.

RANGES

A wide range of sizes is offered: tube diameters from 15mm to 28mm and rod diameters from 6mm to 14mm. Output forces range from 60N (13 lbs.) to 2000N (450 lbs.). A wide selection of end fittings also is available.

Tube bodies are painted in highly corrosion-resistant epoxy enamel, and the piston rods are induction-hardened prior to receiving a durable, hard-chrome-plated surface. Piston rods also may be specified in black nitride or stainless steel.

Each Suspa gas cylinder is manufactured with a specific oil quantity, which serves as a lubricant and damping medium. Relatively higher oil quantites increase damping and also increase the extended-to-compressed force ratio.

FORCES

The required output force can be determined by the diagram (as shown). Proportionately, the piston rod diameter, relative to the tube diameter, determines the extended-to-compressed force ratio (P^1 to P^2 or P^3 or P^4). Flatter ratios require a small piston rod and large tube diameter combination, such as the 16-3 and 16-5.

Longer strokes usually result in lower forces of the gas cylinder, which result in lower forces on the mounting and pivot points.

In applications using extremely long strokes, coupled with high forces, strong consideration should be given to larger piston rod diameters. These offer greater reliability against bending. Side loads always should be avoided.

QUICK-SHIP SERIES

Selected Suspa gas cylinders are offered at economical prices for quick shipment. They comprise the most popular combinations of lengths and output forces and carry Suspa's standard warranty. Ask for details on the QS SERIES gas lift cylinders.

LINEAR DAMPERS

Dampers for speed control have the same construction as Suspa gas cylinders, except for the addition of more dampening oil and the deletion of internal pressure. Damping may be specified on extension, on compression or in both directions.

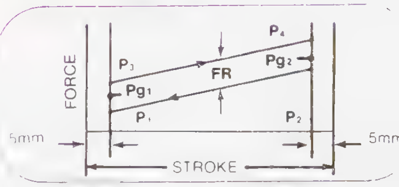
ENGINEERING

Applications can be utilized from -40°C to +90°C. However, due to the laws of physics, the nitrogen gas will expand or contract through the temperature range. This results in an output force change of approximately 3.4% per 10°C.

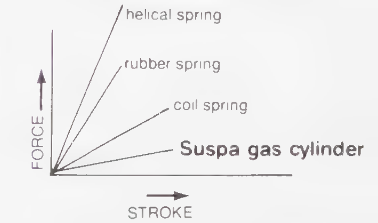
Suspa gas cylinders are manufactured to conform to the highest standards of quality engineering and performance, based upon statistical process control.

As an aid to selecting and specifying Suspa gas cylinders, Suspa has published a pamphlet, *Designing Support,* aimed at simplifying the design process. If you would like a free copy, please ask. We would be pleased to assist you in selecting the appropriate gas cylinder for your intended application. The correct incorporation and application of these Suspa products is the responsibility of the buyer. We reserve the rights to make alterations.

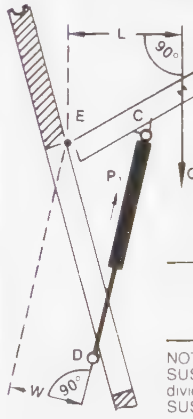
Suspa, Incorporated
3970 Roger B. Chaffee Dr., S.E.
Grand Rapids, MI 49548-3497
616/241-4200 Telex 22-6385
Telefax 616/531-3310



Comparable forces



Force required to maintain lid in open position



$$P_1 = \frac{G \times L}{W} + \text{10-to-15\% safety factor}$$

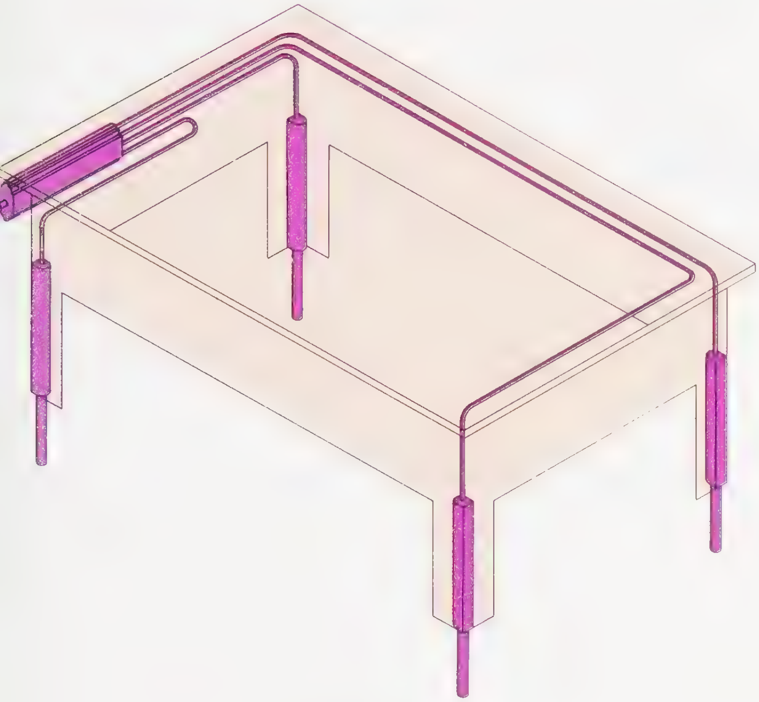
NOTE When using several SUSPA gas cylinders, P_1 is divided by the number of SUSPA gas cylinders

C – Upper mounting point
D – Lower mounting point
E – Pivot
S – Center of gravity
L – Horizontal distance from center of gravity to hinge
W – Effective lever arm of SUSPA gas cylinder = smallest perpendicular distance from gas cylinder to pivot
P_1 = Extended force (on extension)
P_2 = Compressed force (on extension)
P_3 = Extended force (on compression)
P_4 = Compressed force (on compression
FR= Friction

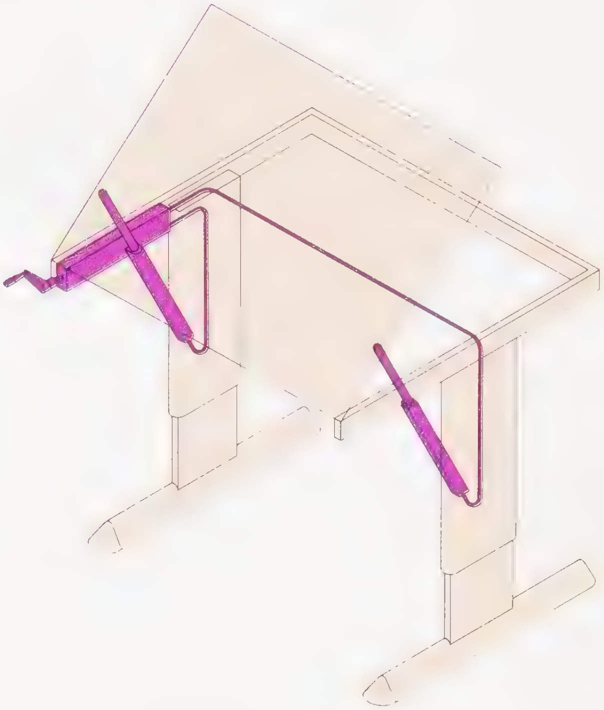
$$\frac{P_3 + P_1}{2} = Pg_1$$

$$\frac{P_4 + P_2}{2} = Pg_2$$

MOVOTEC® Lift Systems from Suspa...



LIFT...



TILT...

A MOVOTEC® Lift System is a compact, versatile height adjustment mechanism. Actually, it's much more than just "a mechanism". *It's a system of various interchangeable components that can be assembled to make a wide variety of lift mechanisms.* Simply choose the desired adjustment range, lift capacity, cylinder(s), and pump from the enclosed menu and leave the rest to us.

A departure from conventional means of height adjustment, a MOVOTEC® fluid-drive system offers a wide variety of benefits...

...for the Designer – Simultaneous activation of anywhere from 1 to 12 cylinders, and load capacities of up to 1,000 pounds, enable a wide range of possible applications.

...for the Engineer – The utilization of flexible tubing, as a means of connecting the pump to the lift cylinders, allows for quick and easy application to just about any size or shape structure.

...for the Operator – Probably the most impressive aspect of the MOVOTEC® system becomes apparent when you use it. Level elevation is achieved with minimal effort, regardless of unbalanced loading conditions, thus making the chore of adjusting a workstation to your individual height or task as simple as the turn of a crank (or the push of a button on motorized systems).

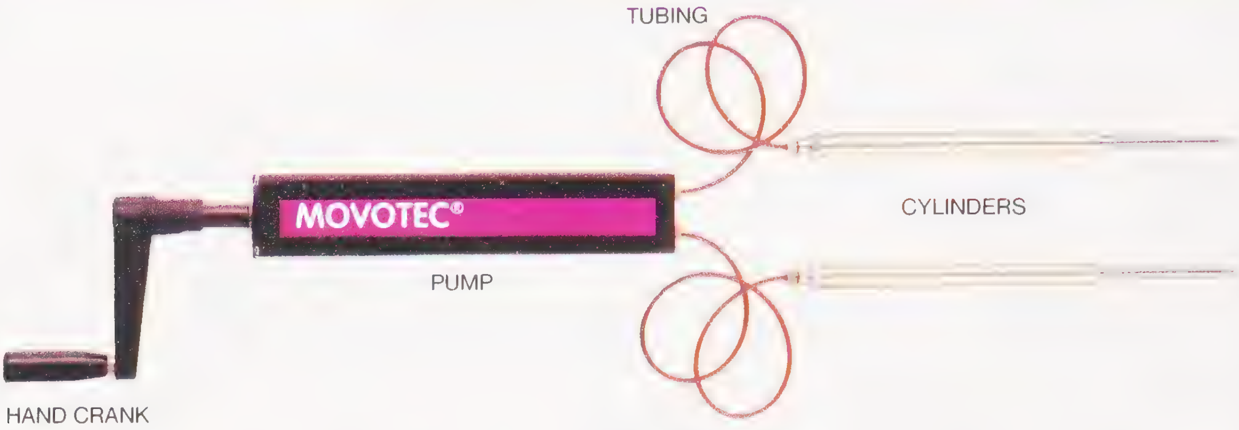
MOVOTEC® systems are commonly used as a means of adjusting the height and/or angle of commercial, industrial, and therapeutic furniture and equipment. However, they have been proven equally suited to a wide variety of other applications where easily-attainable, infinite adjustment is required. In addition to O.E.M. applications, our lift systems can be applied to existing structures (tables, benches, platforms, conveyers, etc.), transforming standard equipment into ergonomic workstations.

SUSPA®
COMPART

Suspa, Incorporated
3970 Roger B. Chaffee Dr., S.E.
Grand Rapids, MI 49548-3497
616/241-4200 Telex 22-6385
Telefax 616/531-3310

Circle 521

. . .leaders in the world of adjustability



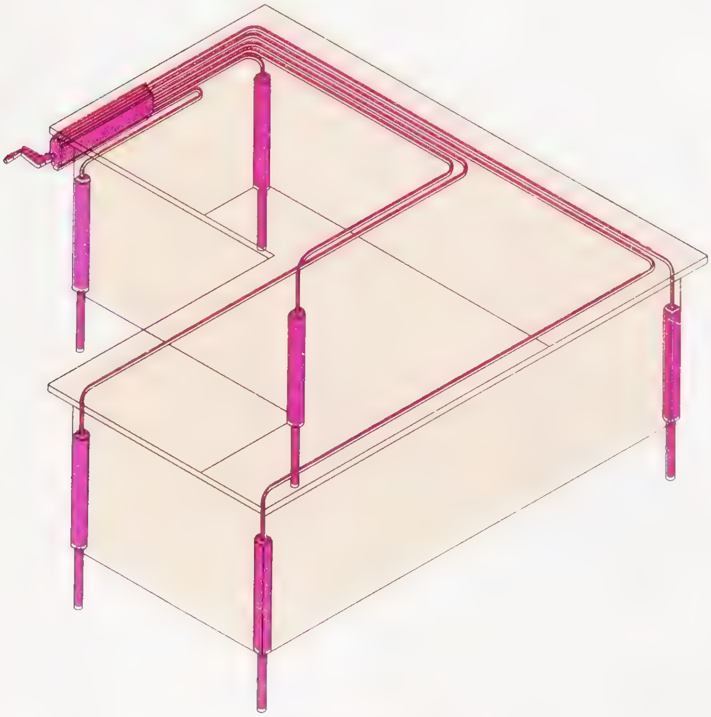
What is a MOVOTEC® Lift System composed of? A MOVOTEC® fluid-drive lift system consists of a pump (the drive mechanism) connected by flexible tubing to a given number of cylinders (the lifting devices).

How do you activate it? By rotating our unique "fold-away" hand crank (shown above), or by pushing a button on our motorized unit (see back page).

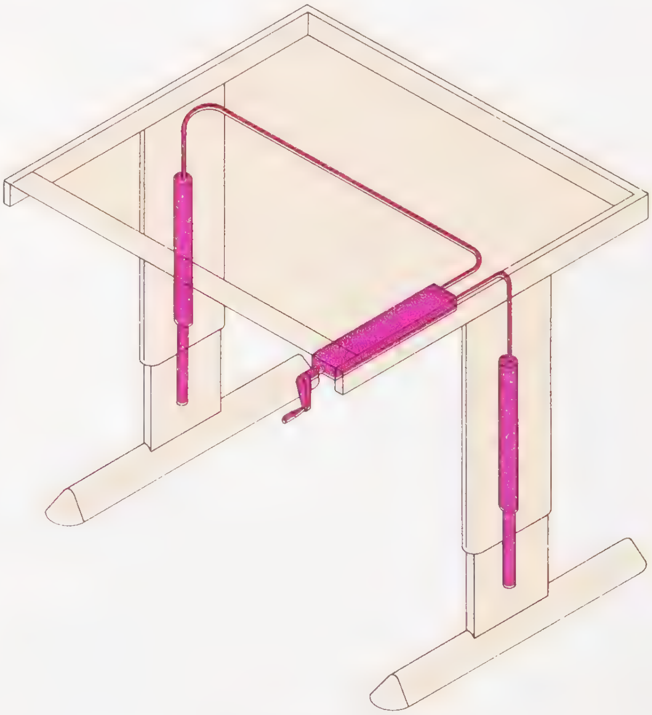
How many cylinders can be activated simultaneously? Our "TB" pumps will activate 1 or 2 cylinders. "PB" pumps can activate from 3 to 6 cylinders. For applications requiring more than 6 cylinders (up to twelve cylinders are currently possible), please contact SUSPA or your representative.

How much adjustment range does a MOVOTEC® system have? We currently offer four "standard" adjustment ranges; 150mm, 200mm, 300mm, & 400mm.

How much weight can a system lift? Actually, we offer a wide range of load carrying capacities, starting from 250 lbs. and increasing to 1000 lbs. Please see our publication "MOVOTEC® System Specification Guide" for complete details.



BOLT ON . . .



. . .OR BUILD IN

Circle 521

Enter Firestone's Innovators Design Contest And Win Up To $5,000!

Firestone's flexible air springs offer significant advantages over conventional actuators and isolators, and they're used in all sorts of industrial and OEM applications.

As a matter of fact, there's practically no limit to how you can use them, but we want to know what *you* think. That's why we're repeating our $5,000 *Firestone Innovators Design Contest.*

Last year's winner, Wes Davidson, design supervisor for MRG Tool & Die Company in Faribault, Minnesota thought up an innovative "check valve lapping" design utilizing a Firestone air spring as an actuator. We thought it was a great idea.

To get your Official Entry Kit, mail the coupon, or give us a call on our toll-free number, 1-800-247-4337. There's no limit to the number of entries you may submit, but the deadline is September 1, 1992.

Firestone
World's Number 1 Air Spring.
FIRESTONE INDUSTRIAL PRODUCTS COMPANY

YES! I want to be a *Firestone Innovator.* Please rush me a copy of the contest rules and all necessary forms and materials.

Name

Title

Company Name

Address

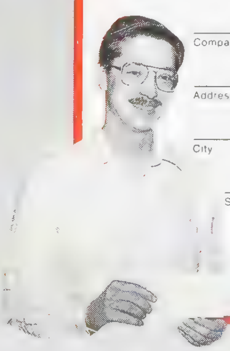
City

State Zip

Mail this coupon to **Firestone Innovators Design Contest**, Firestone Industrial Products Company, 701 Congressional Boulevard, Carmel, IN 46032 or FAX to 317 580 2345

MD/92

Circle 522

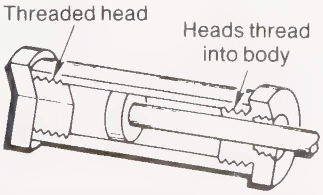


advantage of this type is that working areas of both piston sides are equal. So the piston moves at the same rate and delivers equal forces in each direction. Double-end rod cylinders are available with a hollow rod, so that fluid or another machine element can be passed through the cylinder. In a design variation often used on planers, the hollow piston rod is restrained and the cylinder body is forced back and forth to shift the moving table.

Tie-rod cylinders, the oldest and most common, are typically used in industrial jobs. The cylinder body is held together by four or more tie rods that extend the full length of the body and pass through the end caps or mounting plate. In operation, they may perform any of the common cylinder functions except telescoping.

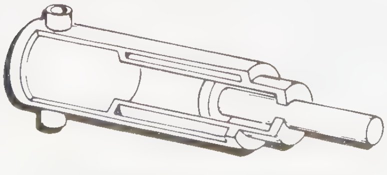
One-piece cylinders are most often used on mobile equipment and farm machinery. The body is either cast integrally, or head and body may be welded together. This is the least expensive type of cylinder; it is compact and simple. But it cannot be repaired when damaged or worn.

Threaded-head cylinders offer a compromise between tie-rod and one-piece units. Threaded units are relatively compact and streamlined, yet can be disassembled for repair by unthreading either or both ends from the cylinder body.



THREADED-HEAD CYLINDER

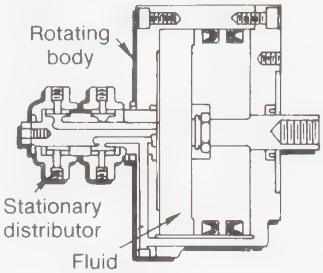
Telescoping cylinders provide a long stroke from a short body. Total stroke length may be as much as four times as long as the collapsed length of the cylinder. Available in either single or double-acting models, telescoping cylinders are widely used for vehicle applications; a typical job is lifting the bed of a dump truck. Force output varies with rod extension: highest at the beginning, when full piston area is used; lowest at the end of the stroke, when only the area of the final stage can be used to transmit force.



TELESCOPING CYLINDER

Diaphragm cylinders are used in either hydraulic or pneumatic service for applications that require low friction, no leakage across the piston, or extremely sensitive response to small pressure variations. They are frequently used as pneumatic actuators in food and drug industries because they require no lubrication and do not exhaust a contaminating oil mist. Spring-return models should not be pressurized in the reverse direction because reversals can pleat the diaphragm and shorten its life. Double-acting actuators with twin diaphragms are available for applications requiring pressure reversal.

Rotating cylinders impart linear motion to a rotating device. They are often used to actuate rotating chucks on turret lathes. Fluid is ported to the rotating cylinder through a stationary distributor. Rotating cylinders are available both with solid and hollow pistons.



ROTATING CYLINDER

Nonrotating cylinders are used in applications that demand both accurate linear position and precise angular orientation. Special guides can be added to standard cylinders to prevent rod rotation, but this is often expensive and unwieldy. More often, twin-rod or rectangular cylinders are used.

Electrohydraulic actuators

The coupling of electronic and hydraulic technology is becoming increasingly common, especially in electrohydraulic actuators. Advances in transducer logic and control capabilities have resulted in cylinders that transmit high forces with a high degree of positioning accuracy. Key to the operation of these actuators is the feedback system. A number of different feedback systems, both mechanical and electrical, are used, depending on the accuracy and durability required.

Linear transducer: One method for accurately sensing cylinder rod position is with a linear displacement transducer. In one widely used system, the transducer housing is mounted to the cylinder end cap, with the sensor rod extending into the hollowed-out piston rod. There is no physical contact between the sensor and cylinder rods.

To determine position, a magnet is attached to the cylinder piston. Current pulses transmitted down the sensor interact with the magnetic field and return a sonic pulse. Distance can be determined by measuring the transmission/reception time interval. Positioning accuracy is 0.001 to 0.003 in.

Hydraulic amplifier: Another way to accurately control position is to hydraulically amplify the motion of a stepping motor. By combining a stepping motor, servovalve, cylinder, and ball screw, positioning accuracy of 0.001 to 0.002 in. and repeatability of 0.0005 in. are possible. Stepping-motor rotation moves a cam to shift the valve spool laterally. This permits oil flow to the cylinder.

As the cylinder piston moves, the ballnut attached to the piston rotates the ball screw, which is connected to the spool. This spool rotation maintains the relative motion of the cam, so the speed of the cylinder is directly proportional to the rotational speed of the stepping motor.

Several choices of ball screws and helical cams provide a selection of servovalve gains and speed ranges to suit most applications. Finer resolution can also be provided through microstepping, which gives standard stepping motors up to 25,000 steps per revolution.

Rotary encoder:A somewhat similar means of control is with a rotary encoder. Here, piston motion again causes ball screw rotation. But in this case, the ball screw is attached to the encoder. Precise measurement of the screw rotation corresponds to a linear piston position. The controller processes this information and signals the servovalve to maintain or change flow accordingly.

Hall-effect sensors: Another approach for position sensing uses a precision-cut square thread on the cylinder rod exterior. After machining, the rod is plated to fill the thread grooves, returning the finish and dimensions to original specifications.

Two Hall-effect sensors, which detect the presence of a magnetic material, are positioned at the rod surface one-quarter thread pitch apart. These sensors "see through" the nonmagnetic chrome plating, but detect the square thread peaks. Output is in the form of two square waves which are 90° out of phase. Accuracy of this system is 0.025 ± 0.005 in.

Mechanical feedback: In one mechanical feedback system, rod displace-

Parker TS-2000 seal designed to eliminate cylinder rod seal leakage.

Parker Series 2H Heavy Duty and Series 3L Medium Duty Hydraulic Cylinders with the TS-2000 seal offers positive protection against cylinder rod leakage under the most demanding applications.

The TS-2000 seal is the product of countless hours of research, development and extensive field testing and is only available on Parker Cylinders.

Based on the popular Parker Serrated Lipseal rod design, the TS-2000 incorporates the pressure-compensated, uni-directional characteristics of a U-cup with the multiple edge sealing effectiveness of compression-type stacked-packings.

The goal for the Parker team was to design a rod seal suitable for all types of applications, regardless of pressure profile. It had to be composed of a material that would not react chemically with hydraulic fluids. And it had to produce better and more reliable "dry rod" performance than the standard serrated lip-seal design in a broad range of applications.

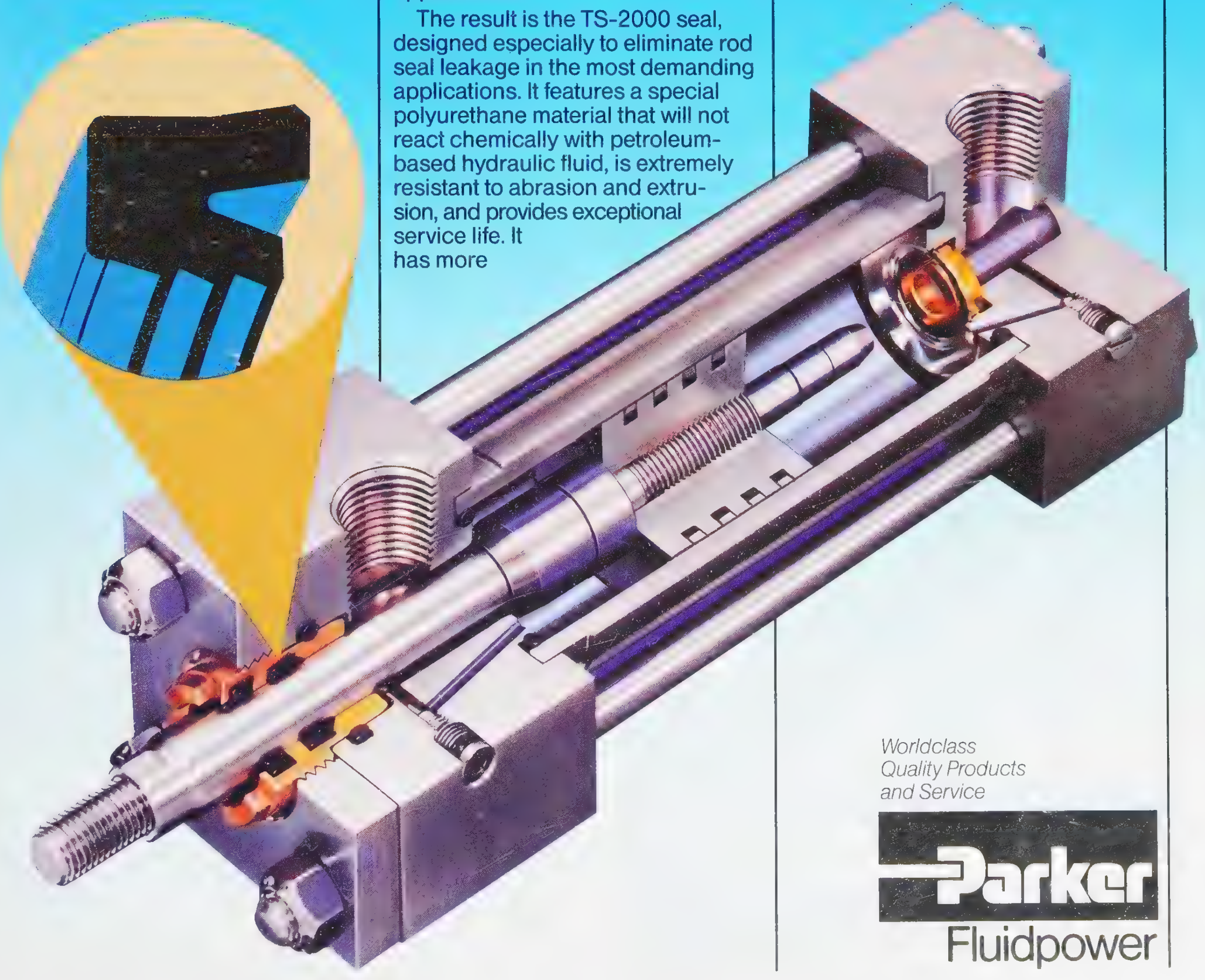
"Jewel" gland with wiperseal and TS-2000 cylinder rod seal.

The result is the TS-2000 seal, designed especially to eliminate rod seal leakage in the most demanding applications. It features a special polyurethane material that will not react chemically with petroleum-based hydraulic fluid, is extremely resistant to abrasion and extrusion, and provides exceptional service life. It has more sealing edges than other seals on the market, which in turn produces "dry rod" performance. The seal geometry was refined for maximum stability in the groove and has excellent performance characteristics throughout a broad range of pressures and piston rod velocities.

The Parker design team was successful!

TS-2000 rod seal has not failed in any of the test applications in the lab or on the job, no matter how tough or demanding.

For more information on the TS-2000 call or write your local Parker distributor or Parker Hannifin Corporation, Cylinder Division, 500 S. Wolf Road, Des Plaines, IL 60016, 708-298-2400.

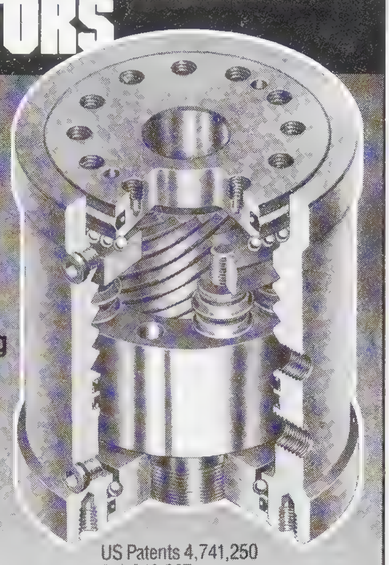


Worldclass
Quality Products
and Service

Parker
Fluidpower

Circle 523

PLANETARY ROTARY ACTUATORS



The PH Series: Unprecedented Features In An Ultra-compact Design

- ► Zero backlash
- ► High load-bearing capability
- ► No drift holding
- ► Economical
- ► 180° and 360°
- ► Sizes available to 27,000 IN-LB
- ► 3000 PSI hydraulic

US Patents 4,741,250 & 4,846,007.
Other US & International Patents Pending.

HELAC® CORPORATION

P.O. BOX 398 • 225 BATTERSBY AVENUE
ENUMCLAW, WA 98022 USA
PHONE: 206/825-1601
FAX: 206/825-1603

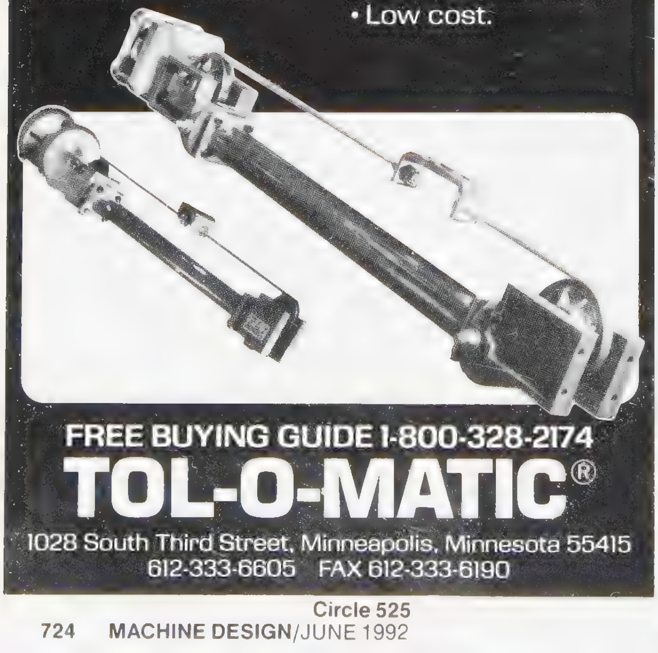
PLANETARY

CALL TOLL-FREE 1-800-327-2589

Circle 524

SPACE SAVING CABLE CYLINDERS

- Tol-O-Matic Cable Cylinders move loads entirely within their own length. They can easily be designed for rotary motion and rounding corners.
- From the first and largest U.S. manufacturer of rodless cylinders.
- Bore sizes from ½ inch through 8 inch. Strokes to 60 feet.
- Low cost.



FREE BUYING GUIDE 1-800-328-2174

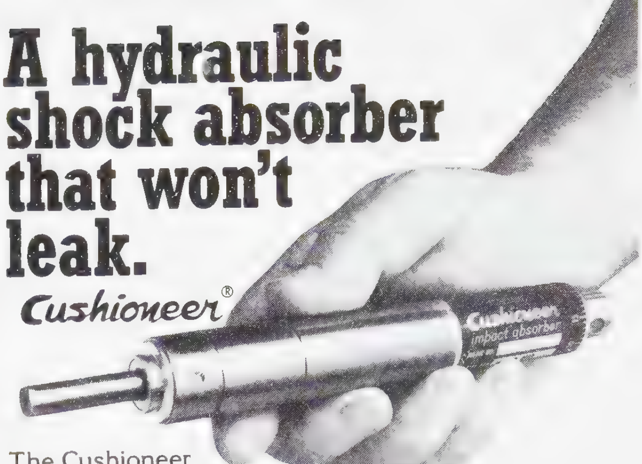
TOL-O-MATIC®

1028 South Third Street, Minneapolis, Minnesota 55415
612-333-6605 FAX 612-333-6190

Circle 525

A hydraulic shock absorber that won't leak.

Cushioneer®



The Cushioneer industrial shock absorber stops gently-moving 5 lb. loads or crashing 1000 lb. loads with equal smoothness. Without variation, these amazing devices operate millions of cycles in trouble-free silence – without leaking even one drop of fluid. Cushioneers speed production and reduce wear in a wide range of applications, including air-cylinder operated devices, robots, flying-die cutoffs – almost anywhere machinery must move fast and stop quickly.

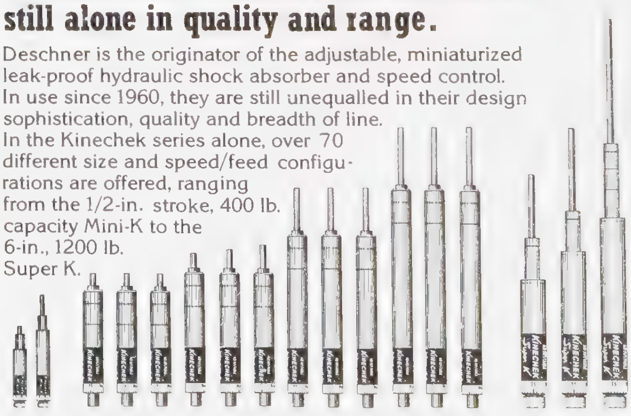
KINECHEK®

Speed/feed control – stays constant over millions of cycles.

Companion to the Cushioneer, the Kinechek regulates the speed of moving devices including air-cylinder piston rods, automatic machine slides, and the feed-rate of drills and other tools. It stays clean and its small size and leak-proof operation make it ideal for use with food processing and medical equipment. business machines and robots. They are easily and quickly adjustable over a 300° range, with excellent constancy due to the sealed design and special long-wearing materials used in their construction.

The Deschner Kinechek and Cushioneer – still alone in quality and range.

Deschner is the originator of the adjustable, miniaturized leak-proof hydraulic shock absorber and speed control. In use since 1960, they are still unequalled in their design sophistication, quality and breadth of line. In the Kinechek series alone, over 70 different size and speed/feed configurations are offered, ranging from the 1/2-in. stroke, 400 lb. capacity Mini-K to the 6-in., 1200 lb. Super K.



FREE! Send for descriptive bulletins on these cost-saving devices.

Deschner Corporation
3211 W. Harvard St., Santa Ana, CA 92704
(714)557-1261 Toll-Free out of state: 800-457-6666

DESCHNER
FLUID POWER

Cushioneer, Kinechek, and Deschner logotype are registered trademarks of Deschner Corp

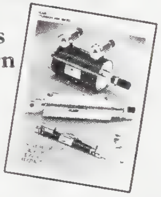
Circle 526

New models!

Specify SPEC® the world's first polymer-constructed compact cylinder

Here's the answer to your space and weight problems. SPEC® (Short, Polymer-Engineered Cylinder) combines a two-piece, precision-molded polymer body with heavy-duty working components. The result is a compact cylinder that is ultra-lightweight, durable and corrosion-resistant. It's also dimensionally interchangeable with many other compact cylinders.

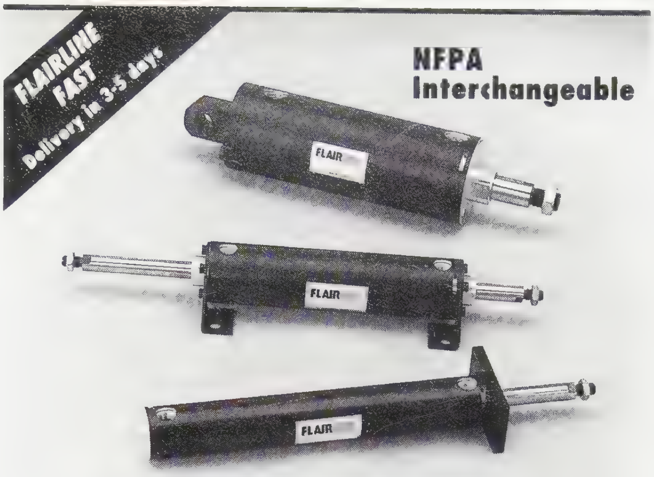
Available in ¾", 1⅛" and 1½" bores including double acting, spring return and magnetic switch models. Call or write for free brochure.



FLAIRLINE®

23435 Industrial Park Dr. ☐ Farmington, MI 48024 ☐ (313) 478-3330

Circle 527

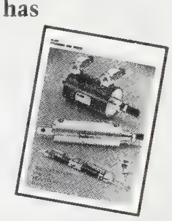


NFPA Interchangeable

Only the tie rods are missing

Eliminating tie rods means Flairline's NFPA interchangeable cylinders save you space, weight and dollars. Outside, the new dimensions give you interchangeable versatility; inside is the same cylinder of proven reliability Flairline has been making for 30 years.

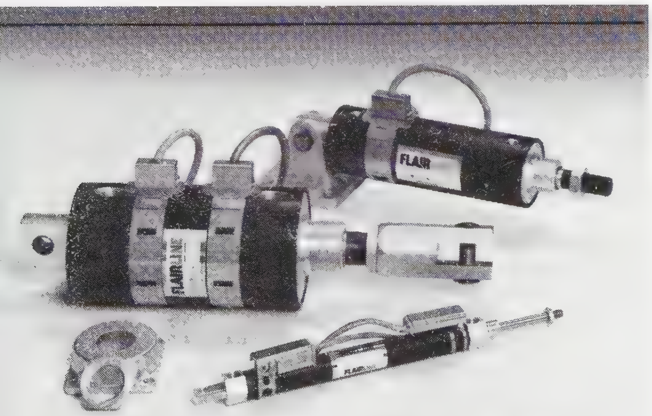
Available in 1½" - 4" bore sizes, pneumatic or low pressure hydraulic, including double acting and double ended models. Ask for free catalog.



FLAIRLINE®

23435 Industrial Park Dr. ☐ Farmington, MI 48335 ☐ (313) 478-3330

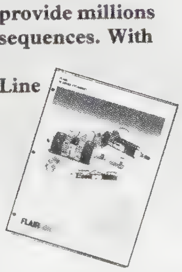
Circle 528



FlairLine Magnetic Switch Cylinders for accurate position signaling

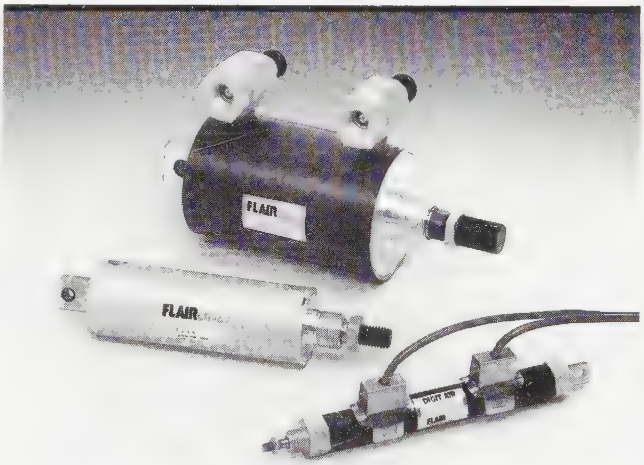
One or more hermetically sealed magnetic switches (Reed, 3 Amp or Hall Effect) can be secured to round body FlairLine cylinders as easy as attaching a hose clamp. FlairLine lightweight, heavy duty cylinders provide millions of trouble free cycles and automated stroke sequences. With our name on the line, yours is not.

For more information, send for free FlairLine Magnetic Switch brochure. For the name of your local distributor, write FlairLine, 23435 Industrial Park Drive, Farmington, MI 48335 ☐ (313) 478-3330



FLAIRLINE®

Circle 529



Flairline/Fast means cylinder delivery in 3-5 days

If it's in our catalog, we'll ship it in 3 to 5 working days. Flairline cylinders are lightweight, heavy duty and priced right. Pneumatic and hydraulic cylinders are available in nine bore sizes, ½" through 4," in any stroke length you need.

Send for free catalog. And ask about SPEC,® the world's first polymer-constructed compact cylinder.

FLAIRLINE®

23435 Industrial Park Dr. ☐ Farmington, MI 48335 ☐ (313) 478-3330

Circle 530

ment is directly proportional to the magnitude and polarity of an electrical input to a force motor. Here, system supply pressure is routed to the control valve and the rod end of the piston. Flow at the control valve passes through two equal size orifices to tank when in a neutral condition. Between the orifices, flow is ported to the cylinder piston. Because flow through two equal orifices gives equal pressure drop, pressure at the piston is one-half supply pressure. The piston is sized to be twice the area of the rod-side area; thus, forces on the piston are balanced.

The valve spool rides in a sleeve, which is held in contact with the follower by a compression spring. Likewise, the follower is held in contact with the feedback cone on the piston. As the piston moves back and forth, the follower moves up and down, forcing the valve sleeve to move through a proportional distance.

An electrical input to the force motor moves the valve spool through a distance and direction corresponding to the magnitude and polarity of the signal. When the spool is displaced relative to the sleeve, it meters flow in or out of the cylinder, causing the piston to move. As the piston moves, the follower rides along the feedback cone, which moves the sleeve until control-valve flow to the piston is shut off. Thus, every value of electrical input has a corresponding rod position.

AIR VS. ELECTRIC

Determining an air motor's suitability for a given task involves reviewing performance requirements, system operating environment, and overall economics. Generally, any of the following conditions or requirements gives a good indication that an air motor deserves serious consideration.

Variable speed: Most ac electric motors run at constant speed. Output speed can be varied only about ±10% of rated speed, and gear reducers or sophisticated controls are required. Using an inexpensive regulating valve, speed of a vane air motor, for example, can be adjusted from 300 to 10,000 rpm.

Variable load: Overloading and stalling can severely damage an electric motor. Air motors are self-cooling and can be stalled indefinitely without damage. Thus, they are a better choice if the motor is subject to variable loads and the possibility of stalling.

Reversible operation: Many air motors are reversible. Because air is compressible, reversal causes little strain on the motor or shock on the load, and is accomplished in a few degrees of rotation. Electric motors, in contrast, generate large amounts of heat when reversed while running. Special cooling provisions make electric motors reversible without damage, but such modifications are expensive.

Compactness: Air motors develop more horsepower per pound and cubic inch than do most standard electric motors. A typical rotary-vane air motor rated for 2.5 hp at 1,800 rpm and 90 psi weighs just 17 lb — one-half to one-third that of a typical electric motor.

Safety: Air motors usually wear out slowly, producing less power as they wear, rather than failing catastrophically. Thus, they rarely cause a safety hazard by abruptly and unexpectedly stopping a machine. Air motors eliminate electrical sparking hazards because they use compressed air as the energy source; explosionproof electric motors require costly special housings.

Harsh environments: Dirt and dust can shorten the life of an electric motor. Higher internal pressure helps prevent contaminants from entering an air motor, resulting in longer life in dusty environments. They also operate safely in wet or corrosive environments.

High ambient temperature: High temperatures limit the performance of an electric motor. An air motor, however, is self-cooling because air traveling through the motor absorbs and carries away large amounts of heat. Air motors perform well at temperatures to 250°F, and some motors are rated to temperatures as high as 400°F.

Cost: Because air motors operate at low pressure (less than 10 psi), they are low-cost devices which are easy to manufacture. A rotary-vane air motor, for example, is about one-half to one-fifth the cost of a comparable electric or hydraulic motor. However, air motors are less energy efficient than their electric counterparts. In a typical air system, an electric motor drives a compressor that supplies air to the motor. Total system efficiency is usually less than 20%. The efficiency of fully loaded, fractional-horsepower induction motors generally ranges from 45 to 70%.

Electropneumatic cylinders

Pneumatics is generally preferred for applications such as material handling, transporting parts, pick-and-place operations, and small-parts assembly. But, until recently, pneumatic systems were almost entirely limited to on/off control — for example, pressure applied or not applied, or a cylinder extended or retracted. However, the need for increased capabilities in automated systems has spurred development of programmable pneumatic equipment, able to produce freely determined rod positions. Advances in closed-loop control theory, development of fast-acting precision pneumatic valves, and the availability of high-speed electronics and user-friendly interfaces now make proportional pneumatics a reality, offering performance that matches closed-loop electrical and hydraulic systems.

One such system features a pneumatic cylinder with a linear position sensor built into the rod, a pneumatic brake, and an electronic controller. Continuous monitoring of rod position and velocity, combined with positive stopping action of the brake, ensures accurate positioning. The system allows up to 32 user-defined set points for each of eight programs. It interfaces to I/O devices such as computers or programmable controllers, or to solid-state relays for timing and output. Typical applications include material-handling, spot welding, and pick-and-place systems. A multiaxis positioning configuration is also offered for control of up to eight axes.

Another type of pneumatic, closed-loop control system features a continuous-acting valve as the control element, along with position sensor and electronic controller. The system contains no mechanical brake. Controlling cylinder movement requires quick and precise valve response. In a positioning application, for example, as the rod approaches the set point, the valve shifts overcenter to build up pressure that opposes cylinder movement. Internal algorithms control rapid shifting of the valve from one side to the other, giving smooth deceleration to the desired position. Variables other than proportional feedback come into play. Thus, the system requires a more powerful microprocessor than typically found in hydraulic servosystems.

As the control element, valve precision and speed must exceed that of

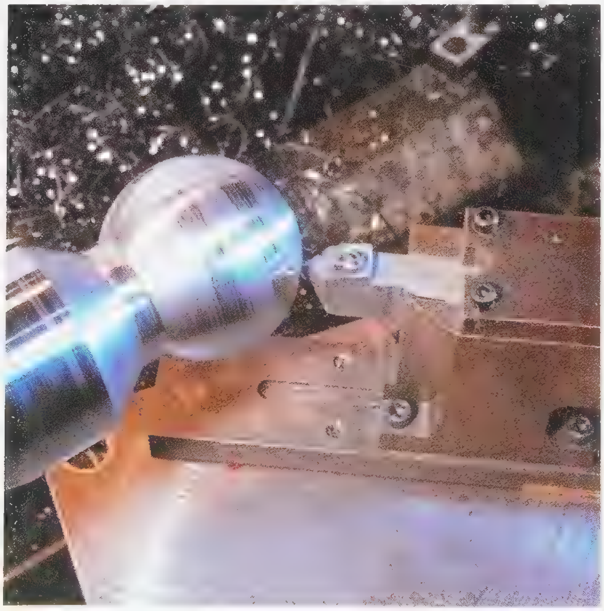
SHEFFER

HYDRAULIC & PNEUMATIC CYLINDERS

SHEFFER...The story behind the "Quality Line"

The Sheffer Corporation manufactures hydraulic and pneumatic cylinders. The products include a wide range of specifications to suit most industrial applications. Cylinder designs offer many choices in pressures, applications and operational media. Price ranges are exceptional.

Standard cylinders are available upon short delivery schedules which can include "off-the-shelf" shipment of popular sizes and styles...two and three-day assembly and shipment of most standard models, customized before assembly to provide customer requirements in mountings, cushions, rod diameters, and stroke lengths.



Custom cylinders are also processed rapidly using the skills of engineering staff members accustomed to accommodating revisions of standard designs for unique requirements. Even complex designs are handled with dispatch.

Large bore sizes and very long stroke cylinders benefit from Sheffer's extraordinary raw material stock required for "extra-sized" units, with bores to 42" and strokes to 45 feet.

Large or small, standard or custom, hydraulic or pneumatic, The Sheffer Corporation is a cylinder specifier's assured first choice as a supplier. With fast response, quality materials, excellence in workmanship, and a sincere desire to provide product value, they are tuned to the customer's need.

The very real benefits of selecting Sheffer cylinders include

- **Longer, trouble-free operation**
- **Easier installation**
- **Faster installation**
- **Less frequent maintenance**
- **Delivery of product when you need it**
- **Expertise in design**

PLUS know-how to provide large units, specialized products for unique applications, and sensible satisfaction of complex requirements.

All competitively priced!

CONCEPT

The Sheffer concept is to deliver VALUE.

Sheffer customers receive **real VALUE**. The price charged for a product is very important to a customer (and Sheffer prices are competitive). But the bottom line is **VALUE**.

- **Does the product represent the expected quality?**
- **Will it do the job?**
- **Must it be reworked or altered?**
- **Is it easy to install and maintain?**
- **Was it received when it was needed?**

A product can be very expensive when production has to be halted, a work crew idled, or a machine cannot be completed and shipped because of the late delivery of a cylinder. What is your idle-time or production down-time worth?

Sheffer **VALUE** begins before the sale. With the experience, expertise and willingness to provide value-added-assistance, we will help to solve that tough application problem. Our exceptional delivery methods cover specials as well as standards, so you enjoy reduced expediting, and can employ tighter scheduling. **VALUE** continues as Sheffer backs up the product wherever it might be located.

MANUFACTURING

Sheffer manufacturing facilities are outstanding in every aspect. Three plants (Cincinnati, Birmingham & Atlanta) are organized for smooth product flow, precision machining, strong control of product quality from material through final assembly.

To achieve the express delivery selections from which a customer can choose, Sheffer has determined accurate planning of material control, efficient raw material flow to machining operations, coordinated assembly, and step-by-step inspections. The resulting product meets Sheffer's quality standards for both physical product characteristics and immediate availability for shipment when promised.

Special adaptations of machine tools, custom-developed assembly work-stations, creative use of space to maintain the elaborate inventory requirements, and training of assemblers for excellent efficiency...all contribute to the sophisticated manufacturing system that delivers dependable fluid power cylinders to meet "on-demand" response to customer requirements.

QUALITY

Quality is an overworked word in the industrial product arena. Everyone claims to have it. Every product is presented as a quality one.

Sheffer means more by "quality" than just a well made product. At Sheffer, quality is an attitude...a way of thinking in every aspect of our business...a goal and a challenge for every employee in every department. Quality is a promise to customers, a criterion against which every company action, policy and procedure is measured. No matter how well we design our products, we're never satisfied, but continue striving for an ever-higher level of performance.

Design, manufacture, delivery, service...whatever we do to provide the right product for the right use at the right price at the right time...our outlook is:

Is this activity Sheffer quality?
What can we do to make it even better?

Quality never ends. It is never fully achieved. It's a flame flickering ahead of us...leading us on to deliver more quality, better quality...Sheffer quality.

There's nothing ordinary about it.

SALES & SERVICE

The Sheffer Corporation, located in Cincinnati, Ohio, Birmingham, Alabama, and Atlanta, Georgia, markets its diverse lines of pneumatic and hydraulic cylinders through a network of distributors who are fluid power experts. They are available in every industrial area of the United States as well as key international locations, and carry other fluid power components to offer full system design and responsibility.

For the Sheffer distributor nearest you, see our distributor list, or consult the Industrial Yellow Pages of your telephone directory.

All Sheffer distributor requests regarding application of Sheffer cylinders are reviewed by a knowledgeable internal sales engineering staff. Our marketing procedures include careful order review and editing to assure both accuracy of information and suitable product application.

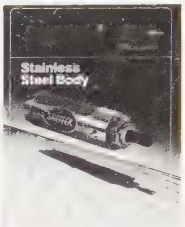
Sheffer maintains microfilm records of all cylinders produced and, at a moments notice, can review the original bill of material to assure that correct replacement parts are supplied, when ordered.

SR SERIES

Stainless Steel Body Pneumatic

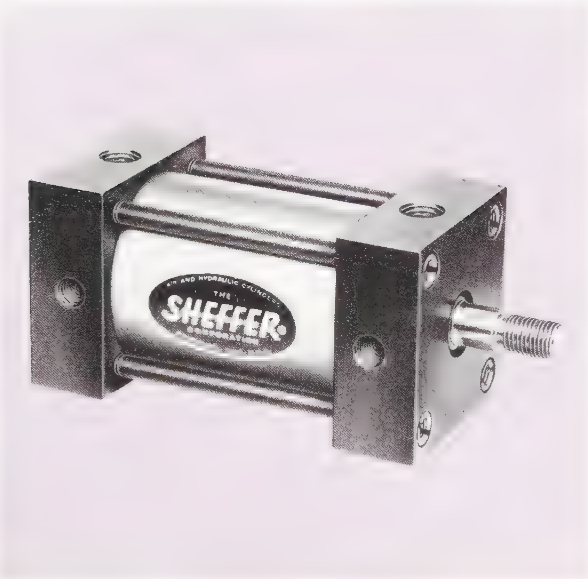
Bore:	7/16″ thru 2″
Rating:	250 psi
Mountings:	15 mounts cataloged

- Interchangeable with other major brands
- Long life stainless steel tubes
- Lubed for life
- Unitized construction for durable, leak proof service
- Reed switch models available
- Bumpers optional


Stainless Steel Body

Circle 632

Request SR Series Catalog



AA SERIES

Economical Aluminum Head Pneumatic

Bore:	1½″, 2″, and 2½″
Rating:	200 psi
Mountings:	Universal mount; mounting kits available

- Aluminum alloy body, head & cap
- Numerous "instant mounting" kits available
- Cushion front, rear, or both ends available
- Piston rod is ground, polished, and hard chrome plated
- Lubed for life
- Modified U-Cup seals for low friction, long life

SHEFFER

Circle 633

Request AA Series Catalog

CL SERIES

Heavy Duty Clamp Pneumatic & Hydraulic

Bore:	¾″ and 1⅛″
Rating:	CLA 150 psi Pneumatic CLH 250 psi Pneumatic/ 1500 psi Hydraulic
Mountings:	Universal mount and stud mount

- Double acting and single acting, spring return
- Numerous accessories for additional mountings
- Lubed for life
- Ideal for all types of clamping and tooling applications
- Very economical
- Modified U-Cup seals for low friction, long life

Heavy Duty Clamp Cylinders
CLA
CLH
CL

Request CL Series Catalog

Circle 634

MA SERIES

Interchangeable Medium Duty Pneumatic

Bore:	1½″ thru 8″
Rating:	200 psi
Mountings:	14 cataloged mounts

- ANSI interchangeable
- Lubed for life
- High tensile, special hard anodized aluminum tube
- Aluminum head and cap for weight reduction
- Economical OEM cylinder
- Cushioned front, rear, or both ends available

SHEFFER

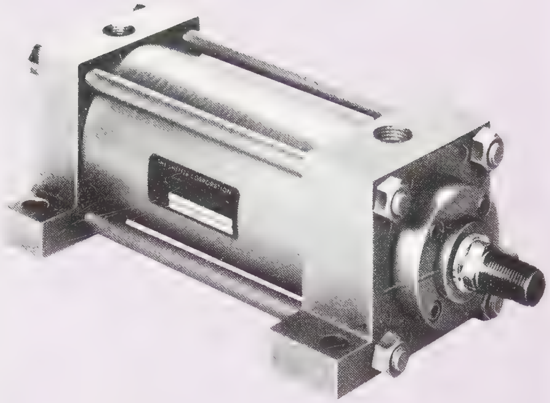
MA

Medium Duty Air Cylinders

200 PSI LUBED FOR LIFE

Circle 635

Request MA Series Catalog

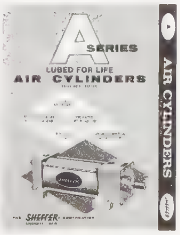


A SERIES

Interchangeable Machined Steel Head Pneumatic

Bore:	1⅛″ thru 14″
Rating:	250 psi
Mountings:	20 cataloged mounts; others available

- ANSI interchangeable
- Lubed for life
- Studded rod ends—4 wrench flats
- Hard chrome plated, case hardened piston rods
- Fast response adjustable cushions
- Ideal for demanding applications



A SERIES

LUBED FOR LIFE

AIR CYLINDERS

AIR CYLINDERS

THE SHEFFER CORPORATION

Circle 636

Request A Series Catalog

C20 SERIES

Economical Cast Head Pneumatic

Bore:	1½″ thru 10″
Rating:	200 psi
Mountings:	5 cataloged mounts

- Extremely compact for limited space applications
- Lubed for life
- Economically priced
- Cushioned front, rear, or both ends available
- Hard chrome plated piston rods standard

SHEFFER C20 SERIES

HEAVY DUTY DOUBLE ACTING AIR CYLINDERS

Circle 637

Request C20 Series Catalog

MH SERIES
Medium Duty Hydraulic

Bore:	1⅛″ thru 8″
Rating:	800 to 2000 psi
Mountings:	20 mounts cataloged; specials available

- ANSI Interchangeable
- Hydrodynamic in-board rod bearing for low friction and long life
- Abrasion resistant polyurethane rod seal and wiper
- No "metal to metal" Slipper Seal piston
- Studded rod end–4 wrench flats
- Adjustable cushions; either end or both ends

Medium Duty Hydraulic Cylinders

Request MH Series Catalog

Circle 638

HH SERIES
Heavy Duty Hydraulic

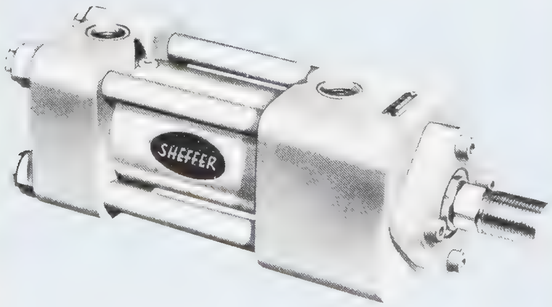
Bore:	1⅛″ thru 24″
Rating:	3000 psi working pressure
Mountings:	22 mounts cataloged; specials available

- ANSI Interchangeable
- Hydrodynamic in-board rod bearing for low friction and long life
- Abrasion resistant polyurethane rod seal and wiper
- No "metal to metal" Slipper Seal piston
- Studded rod end–4 wrench flats
- Adjustable cushions; either end or both ends

SHEFFER
HH
Heavy Duty Hydraulic Cylinder

Request HH Series Catalog

Circle 639



UH SERIES
Ultra Heavy Duty Hydraulic

Bore:	2″ thru 12″
Rating:	5000 psi working pressure
Mountings:	7 mounts standard; specials available

- Hydrodynamic in-board rod bearing for low friction and long life
- Abrasion resistant polyurethane rod seal and wiper
- Rugged duty applications
- Studded rod end–4 wrench flats
- Adjustable cushions; either end or both ends

Circle 640

Request a quotation

WH SERIES
Mobile Hydraulic

Bore:	1½″ thru 6″
Rating:	2000 and 3000 psi working pressure
Mountings:	Pivotal mounts cataloged; others available

- Designed for rugged mobile applications
- Tie-rodless construction
- Unique shear ring assembly for ease of disassembly
- Abrasion resistant polyurethane rod seal and wiper
- No "metal to metal" Slipper Seal piston

Circle 641

Request WH Series Catalog

SHEFFER WH

PP SERIES
Cylinder With Integral Power Unit

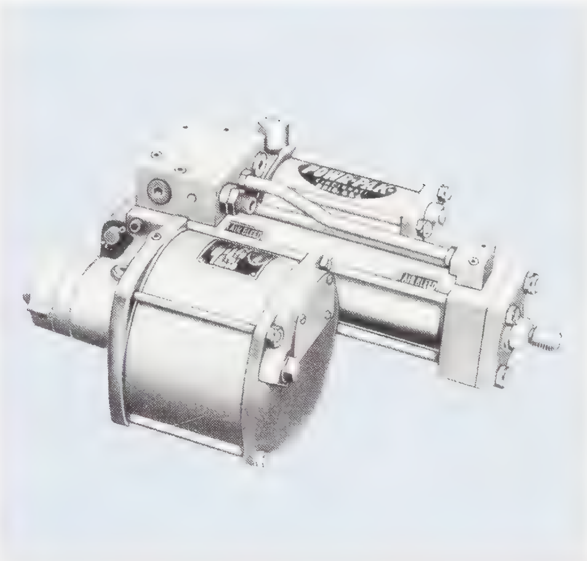
Bore:	2″ thru 14″
Rating:	2000 psi working pressure
Mountings:	8 mounts cataloged

- Complete hydraulic power package
- Ideal for remote applications
- ¾ to 10 horsepower motors
- 4 standard circuits; others available
- Manifold porting—no plumbing by customer
- Only 3 electrical connections for operation

Circle 642

Request PP Series Catalog

SHEFFER
POWR-PAK
HYDRAULIC CYLINDER COMPLETE WITH INTEGRAL POWER UNIT AND AUTOMATIC VALVING
IDEAL FOR SINGLE UNIT, UNUSUAL AND REMOTE APPLICATIONS



OPTIONS, ACCESSORIES, AND SPECIALS

OPTIONS: Sheffer offers cylinders with position feed back devices, end of stroke limit switch actuators, and magnetic limit switch operation. Other options include: cylinders with boots, multi-stage cylinders, precision stroke cylinders, water-hydraulic cylinders, adjustable stroke cylinders, cylinders with thrust keys, spherical bearings, non-rotating rods, vacuum rod seals, rod gland drain backs, etc.

ACCESSORIES: A full line of mounting accessories is cataloged including several devices for achieving good alignment in difficult circumstances.

SPECIALS: Sheffer offers the engineering capability to design special cylinders to satisfy unique operational requirements. Ask us for a quotation.

Circle 643

DISTRIBUTORS

The Sheffer Corporation, located in Cincinnati, Ohio, Birmingham, Alabama and Atlanta, Georgia, markets its diverse lines of pneumatic and hydraulic cylinders through a network of distributors who are fluid power experts. They are available in every industrial area of the United States as well as key international locations, and carry other fluid power components to offer full system design and responsibility. For the Sheffer distributor nearest you, look below, or consult the Yellow Pages of your telephone directory.

ALABAMA

ACTIVATION, INC
153 West Valley Avenue
Homewood
(Birmingham) AL 35259
(205) 942 3096

ACTIVATION, INC.
Two Office Park, Suite 104
Mobile, AL 36609
(205) 342 2102

ALASKA

ALASKA HYDRAULICS, INC
500 West Potter
Anchorage, AK 99518
(907) 562 2217

ALASKA HYDRAULIC, INC.
412 Shelikof
Kodiak, AK 99615
(907) 486-5970

ARIZONA

HYDRAULIC CONTROLS, INC,
214 N 43rd Avenue
Phoenix, AZ 85009
(602) 278-6088

ARKANSAS

FRANKLIN ELECTROFLUID
COMPANY, INC.
8900 Crystal Hill Road
N. Little Rock, AR 72113
(501) 771-4170

CALIFORNIA

HYDRAULIC CONTROLS, INC.
1100 A Hatcher Avenue
City of Industry, CA 91744
(818) 965-9988

HYDRAULIC CONTROLS, INC
4700 San Pablo Avenue
Emeryville
San Francisco), CA 94608
(415) 658-8300

HYDRAULIC CONTROLS, INC
2537 East Jensen Avenue
Fresno, CA 93706
(209) 268-4291

HYDRAULIC CONTROLS, INC.
2323 W El Segundo Blvd
Hawthorne (LA), CA 90250
(213) 757 2246

HYDRAULIC CONTROLS, INC.
845 Industrial Street
Reading, CA 96002
(916) 221-6500

HYDRAULIC CONTROLS, INC
3768 Dalbergia Street
San Diego, CA 92113 3899
(619) 232-1191

HYDRAULIC CONTROLS, INC.
1400 E Scotts Avenue
Stockton, CA 95205
(209) 466-1531

HYDRAULIC CONTROLS, INC
2450 South K Street
Tulare, CA 93274
(209) 688-2911

HYDRAULIC CONTROLS, INC
3481 Industrial Drive
Yuba City, CA 95993
(916) 674-0900

COLORADO

CURTIS FLUID CONTROLS
2170 South Lipan
Denver, CO 80223
(303) 922-4564

CONNECTICUT

PEARSE—PEARSON CO., INC.
22 Tobey Road
Bloomfield, CT 06002
(203) 242-7777

FLORIDA

HYDRAULIC & PNEUMATIC
ENGRG. CO., INC.
1020 N.W. 6th St Bldg E
Deerfield Beach, FL 33442
(305) 429 9560

CALLAHAN FLUID POWER, INC.
5411 West Crenshaw Street
Tampa, Fl 33634
(813) 885 7416

GEORGIA

ACTIVATION, INC.
407A Tift Avenue
Albany, GA 31702
(912) 888 1149

ACTIVATION, INC.
P O Box 1787
Dalton GA 30720
(404) 226 3035

ACTIVATION, INC
2318 Mellon Court
Decatur
(Atlanta) GA 30035 0180
(404) 981 6900

HAWAII

HAWAIIAN FLUID POWER CORP
803 Ahua Street
Honolulu, HI 96819
(808) 833 4516

ILLINOIS

FOSTER, JOHN HENRY INC
1588 North Oakcrest
Decatur, IL 62526
(217) 422-9360

AFFILIATED CONTROL
EQUIPMENT CO., INC
650 Wheat Lane
Wood Dale (Chicago), IL 60191
(708) 595-4680

HEATH ENGINEERING, INC
1890 Manchester Road
Wheaton (Chicago), IL 60187
(708) 653-0031

INDIANA

TEC—HACKETT, INC
120 West Superior Street
Ft Wayne, IN 46802
(219) 424 5504

TEC—HACKETT, INC.
8909 Rawles Avenue
Indianapolis, IN 46219
(317) 895-3670

KANSAS

POWERFLOW SYSTEMS, INC.
3116 Brinkerhoff
Kansas City, KS 66115
(913) 342-7024

KENTUCKY

ENTERPRISE SALES &
PLANNING, INC.
2516 Plantside Dr, Bldg. "C"
Jeffersontown
Louisville, KY 40299
(502) 491-1663

SCOTT INDUSTRIAL
SYSTEMS, INC.
2163 Watterson Trail
Louisville, KY 40299
(502) 266-5050

KENTUCKY HYDRA POWER, INC.
1530 Broad Street
Paducah, KY 42003
(502) 443-6405

LOUISIANA

PNEUMATIC & HYDRAULIC CO.
2443 North Street
Baton Rouge, LA 70802
(504) 343-6693

INDUSTRIAL AIR &
HYDRAULICS, INC.
7400 Townsend Place
New Orleans, LA 70126
(504) 241-7050

MARYLAND

COCHRANE, N.B. COMPANY
2900 Loch Raven Road
Baltimore, MD 21218
(301) 467 4884

COCHRANE, N.B. COMPANY
401 W Summit Avenue
Hagerstown, MD 21740
(301) 790-0500

MASSACHUSETTS

PEARSE—PEARSON CO., INC.
1370 Main Street
Millis, MA 02054
(508) 376-2947

MICHIGAN

BEHCO, INC.
40040 Grand River
Novi (Detroit), MI 48050
(313) 478-6336

FLOOD INDUSTRIES, INC.
623 Industrial Park Drive
Iron Mountain, MI 49801
(906) 779-1500

DEPATIE FLUID POWER CO
301 Peekstok Road
Kalamazoo MI 49003
(616) 381 4590

HYDRO—MECHANICAL
SUPPLY COMPANY
2840 Universal Drive
Saginaw, MI 48603
(517) 799-0423

MINNESOTA

AIR—HYDRAULIC SYSTEMS, INC.
2922 West Superior Street
Duluth, MN 55806
(218) 628 2805

AIR—HYDRAULIC SYSTEMS, INC
504 West 41st Street
Hibbing, MN 55746
(218) 263 9265

AIR—HYDRAULIC
SYSTEMS, INC.
1120 Glenwood Avenue South
Minneapolis, MN 55405
(612) 374-8807

AIR—HYDRAULIC
SYSTEMS, INC.
101 Roosevelt Road
St Cloud, MN 56301
(612) 252 3481

MISSOURI

FOSTER, JOHN HENRY, INC
5019 Rochelle Ct
Springfield, MO 65804
(417) 886-6003

FOSTER, JOHN HENRY INC.
10740 Midwest Industrial Blvd
St. Louis, MO 63132
(314) 427-0600

MONTANA

CATEY CONTROLS, INC
535 Moore Lane
Billings, MT 59101
(406) 259 3703

CATEY CONTROLS, INC
3102 West Broadway
Missoula, MT 59807
(406) 728 7860

NEBRASKA

POWERFLOW SYSTEMS, INC
8945 J Street
Omaha, NE 68127
(402) 331 3104

NEW JERSEY

AIR & HYDRAULIC
EQUIPMENT CO.
21 Kotte Place
Hackensack, NJ 07601
(201) 343 3111

NEW YORK

EARL, RALPH W. CO., INC.
125 Wolf Road
Albany, NY 12205
(518) 458 1269

TRI—STATE SUPPLY
COMPANY OF N.Y.
161 Jamaica Avenue
Brooklyn, NY 11207
(718) 647 1221

EARL, RALPH W. CO., INC.
1 Marine Midland Place
Binghamton, NY 13901
(607) 724-9556

EARL, RALPH W. CO., INC.
2451 Wehrle Drive
Buffalo, NY 14221
(716) 632-2282

EARL, RALPH W. CO., INC.
4498 Sawdey Road
Horseheads
(Binghamton), NY 14845
(607) 796-2277

EARL, RALPH W. CO., INC.
1354 Buffalo Road, #10
Rochester, NY 14624
(716) 235 5320

EARL, RALPH W. CO., INC.
4527 Rt 89
Senaca Falls, NY 13148
(607) 549-7667

EARL, RALPH W CO., INC
930 E Molloy Road
Syracuse NY 13211
(315) 454 4431

NORTH CAROLINA

ACTIVATION, INC
8041-F Arrowridge Blvd
Charlotte, NC 28217
(704) 527-6880

NORTH DAKOTA

AIR—HYDRAULIC SYSTEMS, INC
1517 Main Avenue
Fargo, ND 58103
(701) 237 4129

OHIO

ATLAS FLUID COMPONENTS, INC.
1000 N Main Street
Akron, Ohio 44310
(216) 923-4853

SCOTT INDUSTRIAL
SYSTEMS, INC.
8857 Cincinnati-Dayton Road
West Chester, OH 45069
(513) 793 5992

SCOTT INDUSTRIAL
SYSTEMS, INC.
6740 Huntley Rd., Unit 101
Worthington
(Columbus), OH 43229-1036
(614) 431-0850

SCOTT INDUSTRIAL
SYSTEMS, INC.
272 Leo Street
Dayton, OH 45404
(513) 223-8141

MIDWEST FLUID POWER CO.
5655 Opportunity Dr., Suite 6
Toledo, OH 43612
(419) 478-9086

OKLAHOMA

AIR & HYDRAULIC
COMPONENTS, INC.
420 N. Pennsylvania Avenue
Oklahoma City, OK 73107
(405) 232-3300

AIR & HYDRAULIC
COMPONENTS, INC.
6848 East 41st Street
Tulsa, OK 74145
(918) 663-3661

OREGON

WARDEN FLUID
DYNAMICS CO., INC.
2119 S E Columbia Way,
Bldg 2, #320
Vancouver, WA 98661
(206) 696-4946
(800) 444-4946

PENNSYLVANIA

HILLER, RALPH A. COMPANY
8721 Peach
Erie, PA 16509
(814) 868-8511

HILLER, RALPH A. COMPANY
951 Killarney Drive
Pittsburgh, PA 15234
(412) 882-7353

WINCO FLUID POWER, INC.
750 Penn Ave, #A
Mayfield, PA 18433
(717) 876-1969

WINCO FLUID POWER, INC.
155 Terwood Road
Willow Grove
(Philadelphia), PA 19090
(215) 657-4940

TENNESSEE

FRANKLIN ELECTROFLUID
COMPANY, INC.
3844 Watman
Memphis, TN 38118
(901) 362-7504

ACTIVATION, INC.
325 Plus Park Blvd #102
Nashville, TN 37217-1022
(615) 889-8472

TEXAS

INDUSTRIAL AIR &
HYDRAULICS, INC
3401 E Randol Mill Road
Arlington, TX 76005
(800) 772-5306

BURTON BEARING &
INDUSTRIAL INC.
3800 International Blvd
Brownsville, TX 78521
(512) 542-3578

HYDRA POWER SYSTEMS, INC.
11201 Rojas Drive
El Paso, TX 79935
(915) 593-2636

INDUSTRIAL AIR &
HYDRAULICS, INC
1901A Johanna Dr
Houston, TX 77055
(800) 899-7122

UTAH

HYDRAULIC CONTROLS, INC
4477 S 500 West
Salt Lake City, UT 84123
(801) 261-2700

VIRGINIA

WEAVER, C ARTHUR CO., INC
2430 Alabama Avenue
Norfolk VA 23513
(804) 857 8700

WEAVER, C. ARTHUR CO., INC
2420 Grenoble Road
Richmond, VA 23294
(804) 672-6501

WEAVER, C. ARTHUR CO., INC.
7562 Hi Tech Road
Roanoke, VA 24019
(703) 563-9761

WASHINGTON

WARDEN FLUID
DYNAMICS CO., INC.
203 North 36th Street
Seattle, WA 98103
(206) 633-0382
(800) 666-0382

WARDEN FLUID
DYNAMICS CO., INC.
East 5603 Broadway
Spokane, WA 99212
(509) 534-2880
(800) 234-8265

WEST VIRGINIA

SCOTT INDUSTRIAL
SYSTEMS, INC.
3002 First Avenue
Nitro (Charleston), WV 25143
(304) 755-8158

WISCONSIN

PRICE ENGINEERING CO., INC.
631 North Voelker
Depere, WI 54115
(414) 336 1211

PRICE ENGINEERING CO., INC
N5605 Valley Creek Road
Fond du Lac, WI 54935
(414) 921 7021

AIR—HYDRAULIC
SYSTEMS, INC.
2743 Larson Street
La Crosse, WI 54603
(608) 781-7255

PRICE ENGINEERING CO., INC.
1440 N Dousman Road
Oconomowoc, WI 53066
(414) 567 3345

PRICE ENGINEERING CO., INC.
22577 Johnson Drive
Waukesha, WI 53186
(414) 547 2700

PRICE ENGINEERING CO., INC.
3101 Highway O', North
Wausau, WI 54401
(715) 675 2680

CANADA

HYPOWER SYSTEMS CORP
8616 18th Street
Edmonton, Alberta T6P 1K5
(403) 449-0600

CAN—ACT CYLINDERS
& CONTROLS
270 S W Marine Drive
Vancouver, British Columbia V5X 9
(604) 324-6388

HYPOWER SYSTEMS, LTD.
11 Terracon Place
Winnipeg, Manitoba R3C 4E6
(204) 231 2328

COWPER, INC
311 Rothesay Avenue
St John New Brunswick E2L 3Z8
(506) 634 7763

COWPER, INC.
32 Glendale Avenue, #4
L Sackville, Nova Scotia B4C 3J7
(902) 864-2480

RUBBERLINE PRODUCTS, LTD
33 Manitou Drive
Kitchener, Ontario N2G 3Y9
(519) 894-0400

COWPER, INC.
759 Progress Ave, Unit 1A
Kingston, Ontario K7M 6N6
(613) 389-5706

COWPER, INC
117 Consortium Ct
London, Ontario N6E 2S8
(519) 681-0430

COWPER, INC.
1109 Derry Road East
Mississauga, Ontario L5T 1P3
(416) 670-3488

COWPER, INC.
1 Grenfall Crescent, #201 1
Nepean (Ottawa), Ontario K2G 0G
(613) 727-0220

COWPER, INC.
677-7th Avenue
Lachine, Quebec H8S 3A1
(514) 637-6746

COWPER, INC.
2300 Rue Leon Harmel, #104
Quebec, Quebec GIN 4L2
(418) 527 9292

LICENSEES

AUSTRALIA

DELTA HYDRAULICS
171-179 Stony Rise Rd
Devonport 7310
Tasmania, Australia
011-61-04-245-711
FAX 011-61-04-246-983

ENGLAND

HELIPEBS CONTROLS LIMITED
Sisson Road
Gloucester GL2 ORE
England
011-44-452-423-201
FAX 011 44-452-307-665

THE
SHEFFER
CORPORATION

Sheffer Corporation
6990 Cornell Road
Cincinnati, Ohio 45242
(513) 489-9770
FAX (513) 489-3034

POLICY: The policy of The Sheffer Corporation is one of continual improvement in design and manufacture to assure still finer products, hence, specificatio
subject to change without notice

LIMITED WARRANTY: Sheffer warrants its products to be free from defects in material and workmanship for a period of one year from the date of shipment
warranty does not cover field labor charges for parts removal and replacement, adjustments, repairs or other work, corrosion, electrolysis, mineral deposits
normal deterioration, misapplications, modification, or change in original operating conditions, components supplied by others, defects in parts resulting f
abuse, negligence, neglect, accident, fire or explosion, or seals and other components subject to normal wear

The sole and exclusive remedy against Sheffer shall be for the repair or replacement of parts returned transportation prepaid to Sheffer's factory and found
Sheffer to be defective. Replacement parts provided shall not extend the warranty period for said parts or for the total unit

**IN CONSIDERATION OF THIS EXPRESS WARRANTY NO OTHER REMEDY (INCLUDING BUT NOT LIMITED TO INCIDENTAL OR CONSEQUENTIAL DAMAGES) SHALL
AVAILABLE. THIS WARRANTY SHALL BE IN LIEU OF ANY AND ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, ANY IMPLIED
WARRANTY OF MERCHANTIBILITY OR FITNESS FOR A PARTICULAR PURPOSE, AND OF ALL OTHER OBLIGATIONS ON THE PART OF SHEFFER.**
Sheffer neither assumes, nor authorizes any person to assume for it, any other obligation or warranty.

Machine Design reprints mean business.

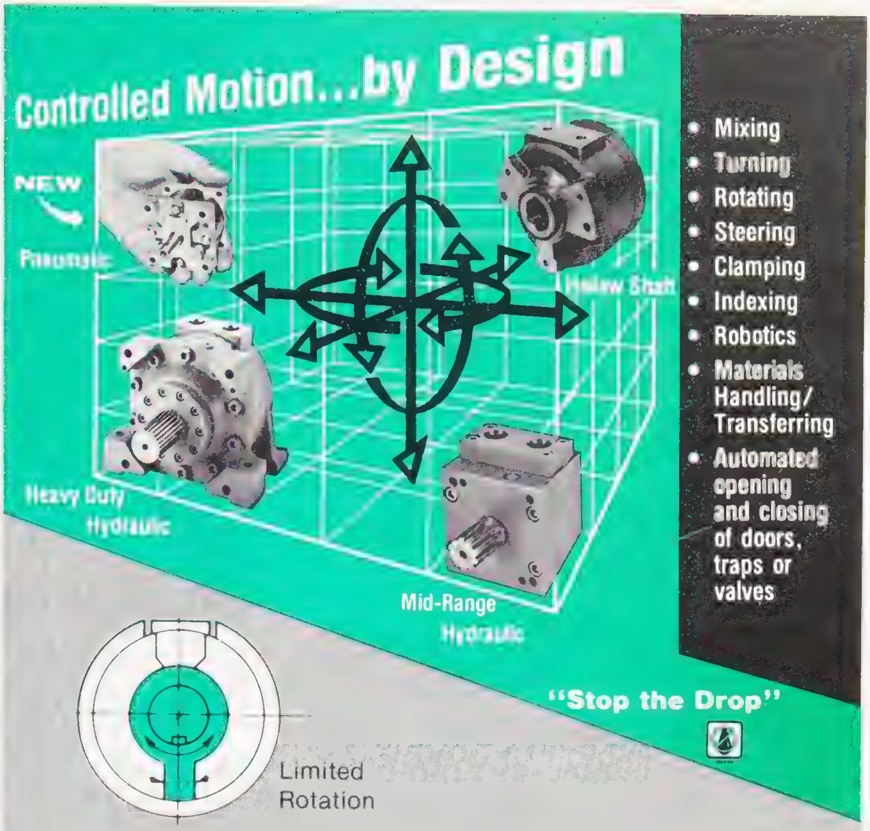
Let us put them to work for you.

Reprints of your advertisements and "Machine Design" articles can be used as:

- *Direct mail to customers and prospects.*
- *Sales aids for your people in the field.*
- *Tools to inform stockholders and employees.*
- *Training aids for new employees.*
- *Handouts at trade shows and company meetings.*
- *New product announcements.*
- *Follow-ups to ad inquiries.*

For more information about this cost-effective way to get your message out to your customers and staff or to place an order, call Linda L. Fouts, reprints manager, at (216) 696-7000.

MACHINE DESIGN
is a publication of:
Penton Publishing
1100 Superior Avenue
Cleveland, Ohio 44114



- Mixing
- Turning
- Rotating
- Steering
- Clamping
- Indexing
- Robotics
- Materials Handling/Transferring
- Automated opening and closing of doors, traps or valves

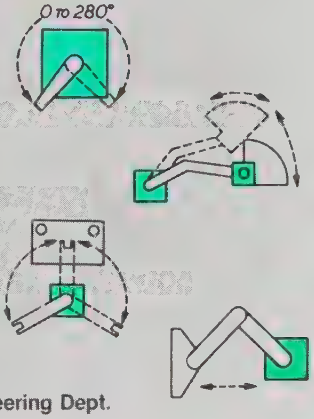
Hydraulic & Pneumatic Rotary Actuators

ROTAC® Hyd-ro-ac

As a product design engineer, you appreciate the need to control mechanical motion and costs while maintaining design flexibility. ROTAC HYD-RO-AC rotary actuators fill these needs. They provide consistent, precise and versatile motion control, whatever the application—

Rotary actuators, in various sizes and capacities, are designed for the designer. Stationary shoe, fixed vane to a center shaft, and completely sealed construction give you a compact, durable unit that produces 280° of virtually instant torque in either direction. They can be mounted at the base, end, foot or flange.

For controlled motion and design flexibility, specify ROTAC HYD-RO-AC fluid power rotary actuators.



For details, contact the Actuator Sales Engineering Dept.

Micro-Precision TEXTRON

Micro-Precision Operations Inc./Subsidiary of Textron Inc.

525 BERNE STREET • BERNE, INDIANA 46711
219/589-2136 • TWX 810-323-1581 • FAX 219/589-8966

See our catalog in THOMAS REGISTER

Circle 532

the control loop as a whole. Valve speed determines how rapidly the system compensates for unwanted deviations. A rule of thumb that governs the stability of closed-loop control requires the valve natural frequency to be at least three times that of the controlled system, for example, the cylinder and load. Large-diameter, short-stroke cylinders could pose control difficulties. But for most material-handling applications, cylinder natural frequencies in the 1 to 5-Hz range are well within the capabilities of pneumatic control valves.

When free programmability and multiposition capabilities are not important, lower-cost options are available. Most pneumatic cylinder manufacturers offer piston or rod position sensing capability with their product, enabling the user to interface with electronic controls. One common method is the mechanical limit switch, although this device seems to have fallen into disfavor. The drawbacks most often cited are the susceptibility of mechanical parts to damage or wear, and that the switch gets in the way of machine operation. More often, proximity switches mounted to the cylinder OD are used. These provide noncontact indication of cylinder piston position.

One type of proximity switch is an enclosed reed switch that is activated by a permanent magnet mounted to the piston. As the piston approaches, the magnetic field closes the switch, completing an electric circuit and producing an electric signal. Others prefer to use Hall-effect sensors in combination with a piston-mounted magnet.

The main difference between these two devices is that a reed switch is a mechanical device, while a Hall-effect switch is electronic, with no moving parts to wear out. Reed switches have the advantage of operating on ac or dc current; Hall-effect switches are limited to dc only. Also, reed switches are about half the price of their electronic counterpart, although the price differential is decreasing. On the other hand, Hall-effect devices react much faster than reed switches, on the order of 100,000 vs. 500 Hz. It is a waste of money to install microprocessor-based logic, and then be hampered by a slow switch. Overall, the trend seems to be towards these solid-state devices.

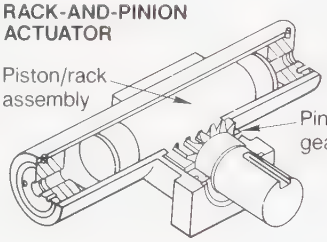
Both switches have a repeatability of 0.005 in. or less. But often rod velocity, not switch accuracy, determines the overall repeatability of rod position. Because air is a compressible fluid, precise positioning of the cylinder rod — especially in midstroke — is difficult, regardless of the switch used. In many applications, even if the switch is very fast and accurate, getting the valves to react fast enough may be the real problem. In such cases, mounting fast-acting valves as close to the cylinder as possible is important. This eliminates excess compressible air in the lines between cylinder and flow control, giving more precise control.

Rotary actuators

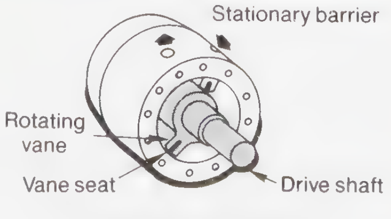
Rotary actuators produce oscillating power by rotating an output shaft through a fixed arc. They are compact, simple, and efficient. They produce high instantaneous torque in either direction and require only a small space and simple mountings.

Rack-and-pinion actuators use fluid pressure to drive a piston connected to a gear rack, which rotates a pinion. Standard units are available with rotation of 90, 180, or 360°. They can be obtained with two parallel piston-rack units to double output torque. Outputs to 35 million lb-in. are available.

RACK-AND-PINION ACTUATOR



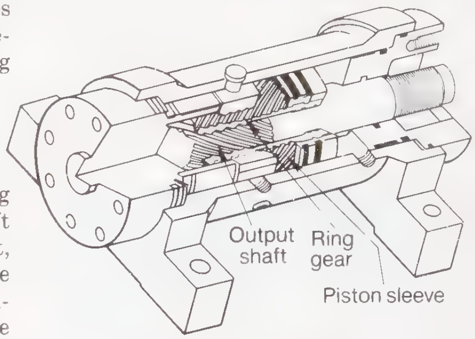
Vane actuators consist of a shaft mounted in a cylindrical housing, with one or more vanes attached to the shaft. Applying fluid pressure to the vanes produces shaft rotation. An internal barrier between housing OD and shaft divides interior volume into two chambers. For this reason, single-vane actuators are normally limited to about 280° of rotation, and double-vane actuators to about 100°. Torque is directly proportional to vane area and effective fluid pressure. Vane actuators have torque outputs as high as 500,000 lb-in.



VANE ACTUATORS

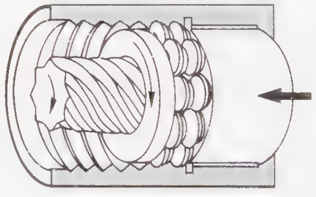
Helix actuators have helical grooves in the piston rod that convert linear to rotary motion. Helical actuators are available with standard rotations varying from 100 to 370° with outputs to 15,000 lb-in.

A relatively new actuator gaining wide acceptance uses double helical gearing. This design features two moving parts: the piston sleeve, which reciprocates and rotates; and the output shaft, which only rotates. As the piston sleeve reciprocates in helical actuators, the outer spline engages the ring gear and causes sleeve rotation. At the same time, the inner spline engages another set of helical teeth on the output shaft. This causes relative shaft rotation in addition to that of the piston sleeve.



HELICAL ACTUATORS

Planetary actuators increase helix angle and reduce actuator length by replacing sliding action with rolling action. Planetary rollers on the piston between the helical shaft and housing grooves provide an arrangement similar to the gears in a planetary speed reducer. As in double helical actuators, planetary actuators have two basic moving elements, the piston assembly and shaft assembly.



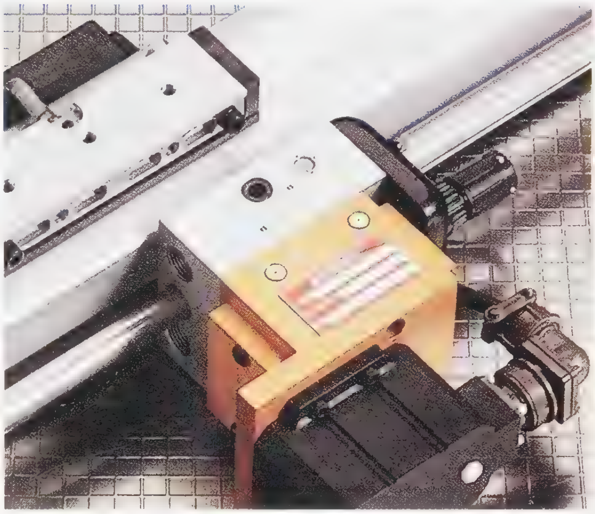
PLANETARY ACTUATOR

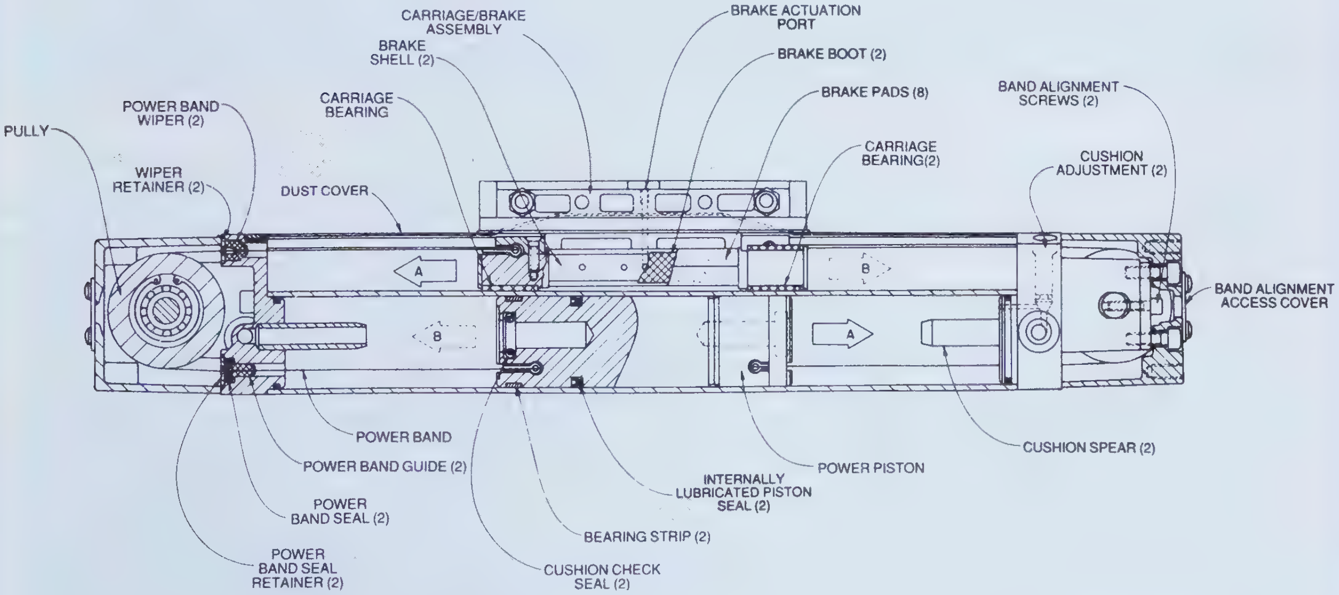
Piston movement causes rollers to follow helical grooves in the housing, forcing piston rotation. Simultaneously, the rollers follow helical grooves in the shaft, forcing shaft rotation. Design is such that 90° piston movement results in 180° of shaft rotation. Large-diameter bearings and mounting flanges on this unit can carry large moment, thrust, and radial loads.

Linear cylinders consist of a simple cylinder with a pin-ended rod connected to a crank arm that drives the rotating shaft. These devices are typically pressure actuated in both directions and are equipped with adjustable stops for accurate adjustment of

PNEUMA-SERV™...

A linear positioning system with repeatabilities to ±.002 inches. It is the cost effective solution to comparable hydraulic, servo-motor and stepping motor arrangements.



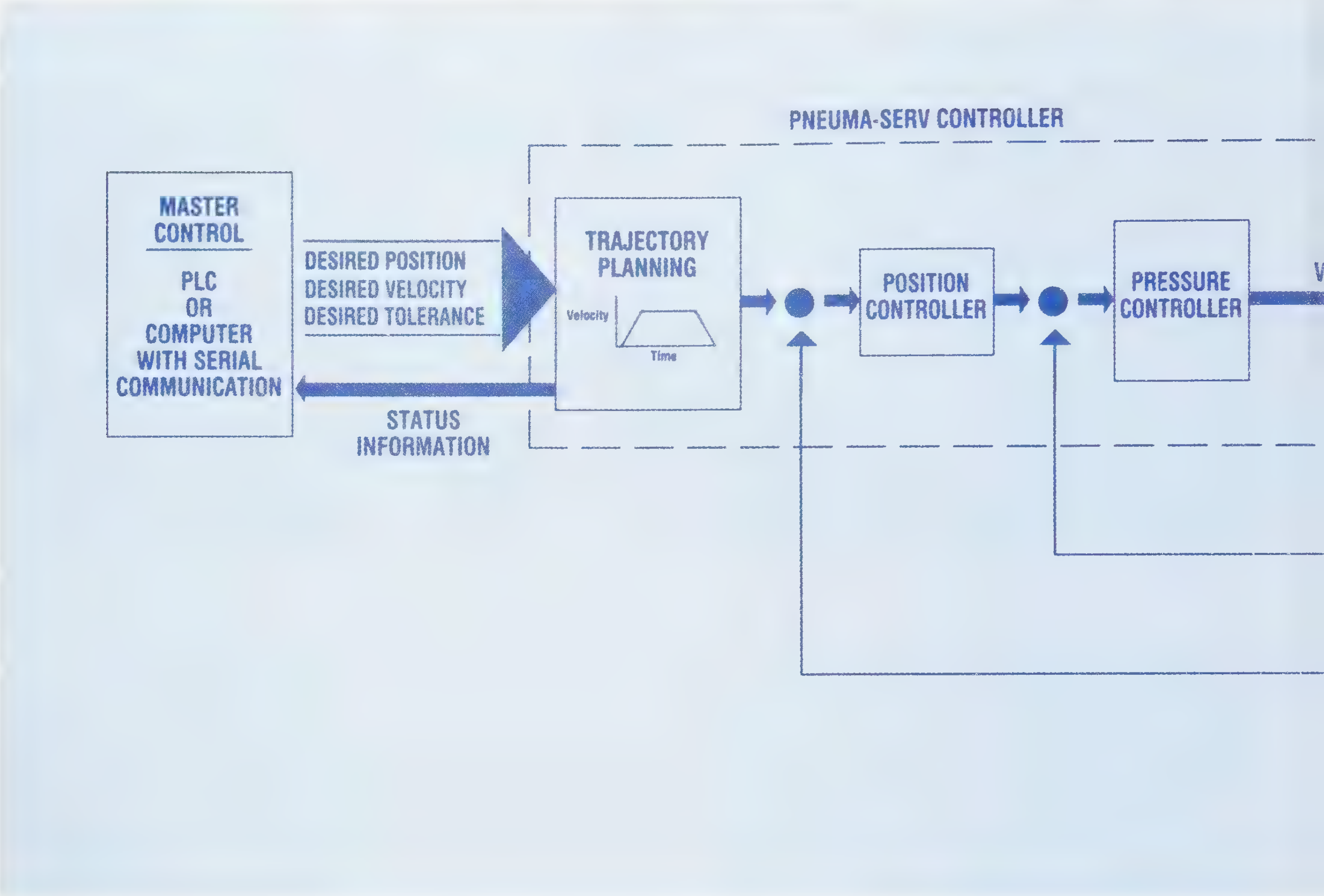


MOSIER

MOSIER INDUSTRIES, INCORPORATED

Circle 533

PNEUMA-SERV™ System Overview



The Pneuma-Serv™ controller is a user friendly interface with all programming and set-ups being menu driven. All functions are entered or changed by simply answering the displayed questions.

When programming is completed, the Pneuma-Serv™ controller, (upon receiving commands from a master controller), sends a signal to a high performance proportional valve indicating the amount of air pressure that is allowed to pass through the valve. Constantly varying air pressures are supplied to both of the cylinder ports.

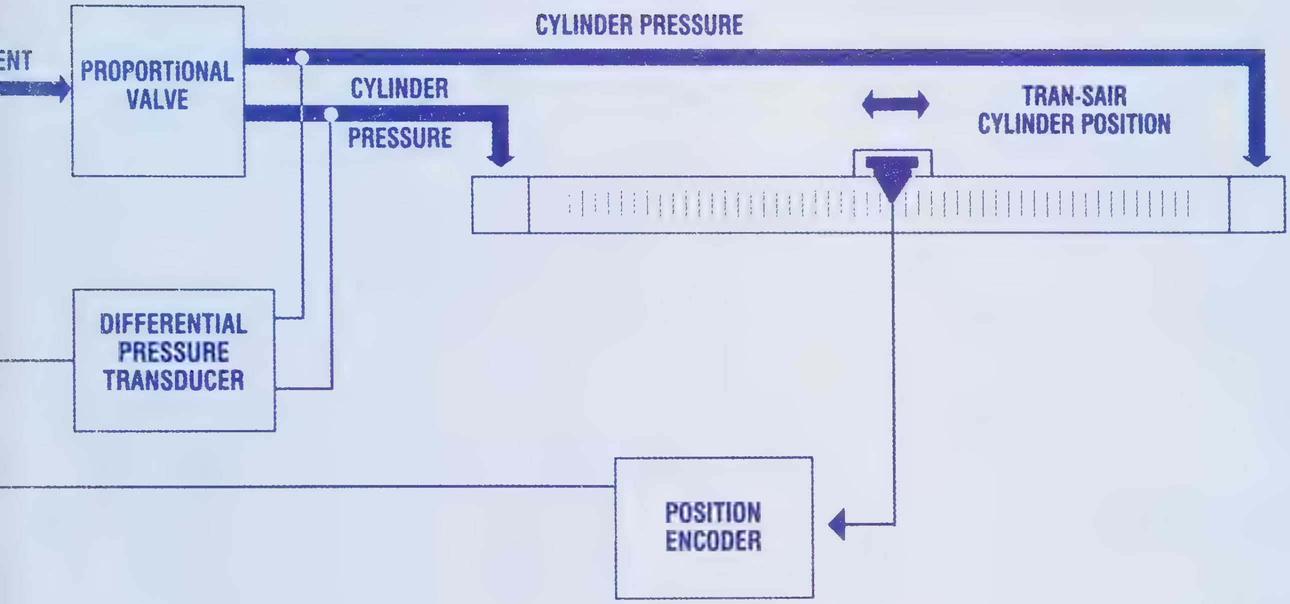
A pressure transducer monitors the actual output of the proportional valve and sends a continuous signal back to the Pneuma-Serv™ controller. The controller then compares the actual output of the proportional valve with the intended signal and makes any necessary adjustments. The cylinder responds to these pressure adjustments and moves accordingly.

A high performance magnetic encoder strip is mounted on the side of the cylinder. It continually sends a signal back to the Pneuma-Serv™ controller indicating the exact position of the load. The strip has an accuracy of .010 inches per 10 feet of travel.

The Pneuma-Serv™ linear positioning system is a closed loop positioning system, which means that the actual position of the load is continuously compared to the desired position. The valve signal is adjusted accordingly.

After the load has reached the desired position, the Pneuma-Serv™ controller sends a signal back to the master controller indicating that the move has been completed.

Because the Pneuma-Serv™ software is adaptive, the weight of the load can be changed at each stop position and the system will recognize the change and make the necessary adjustments to maintain the positioning repeatabilities.



Patents Pending

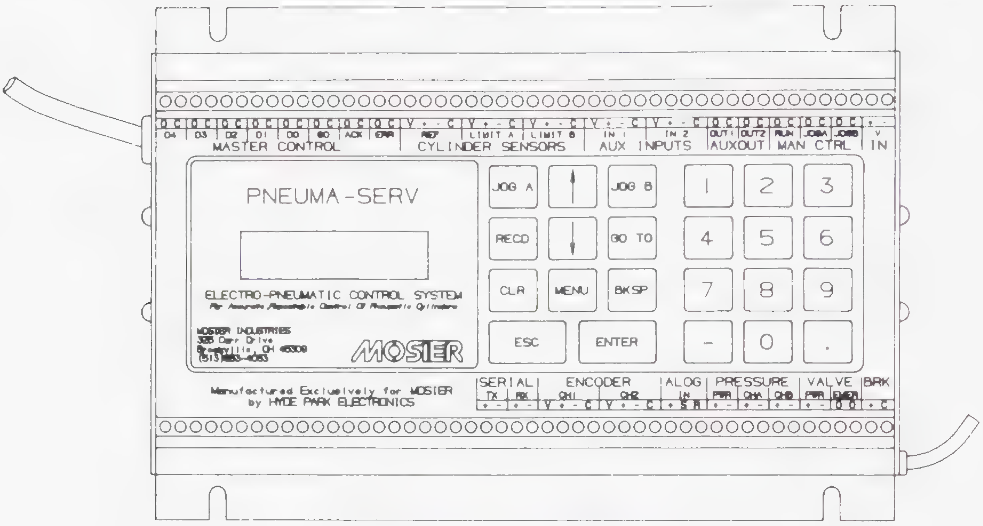
Facts and Figures

- Adaptive - automatically self-adjusts to variations in load, velocity, and performance characteristics. Even adjusts to piston seal wear to ensure optimum system performance.
- High performance 4-way proportional valve produces accurate air flow to achieve desired performance parameters.
- All programming and set-up is menu driven.
- Discrete input in binary coded decimal format (BCD) or serial communication (RS232).
- Programmable in either English (inches, psi and pounds) or metric (millimeters, bars and kilograms) units.
- Internal memory accepts 29 sets of move information including velocity, position and tolerance parameters for each step.
- EEPROM stores program parameters during power down.
- Internal diagnostics for troubleshooting hardware problems.
- Magnetic position feedback encoder has a non-contact reading head for a stable measurement signal.
- Operates on standard air supply of 40 to 100 psi.
- Stroke lengths of 1 inch to 14 feet.
- Accurate to ±.010 inches per 10 feet of travel.
- Repeatability of ±.002 inches.

Circle 533

PNEUMA-SERV™ Programming

The Pneuma-Serv™ is menu driven and prompts the user through all programming and configuration information. The Main Menu has seven program modes that the user may select from. The menu is displayed on the CRT screen of the master controller or terminal, or on the LCD display of the keypad version Pneuma-Serv™ controller.



Main Menu

Parameter Set-up

Configuration information is entered by answering questions about your specific application. Typical questions that are asked are: System Air Pressure?; Cylinder Orientation?; Output Configuration (sinking or sourcing)?; etc.

Diagnostics

A series of diagnostics displays are available for installation and troubleshooting. Diagnostics allows that status of the inputs to the controller to be displayed or the outputs from the Pneuma-Serv™ controller to be directly controlled.

Homing

The incremental encoder used with the Pneuma-Serv™ system requires a home location input. A software routine to execute the homing function can be initiated from the PLC interface, the RS232 serial interface, or from this entry from the main menu.

Friction Analysis

The friction forces of the cylinder and load affect the automatic "tuning" of the Pneuma-Serv™ system. The friction analysis routine cycles the Tran-Sair™ cylinder between designated positions at different velocities to calculate these forces. The friction values used in this routine are automatically updated when the routine is completed.

Slave Mode

While the Pneuma-Serv™ is in the slave mode, commands can be sent from the master controller to the Pneuma-Serv controller to position the cylinder.

Program Mode

Information for up to 29 stations can be entered and stored while the controller is in the program mode. Each station position has a corresponding traverse velocity and positioning tolerance. The programmed information is stored in the EEPROM when you exit the program mode.

Command Mode

Direct control of the cylinder position is available to the operator from the command mode. The Pneuma-Serv™ can be commanded to an entered position or moved with the Jog keys. The cylinder position can be manually jogged in increments as small as .0004 inches.

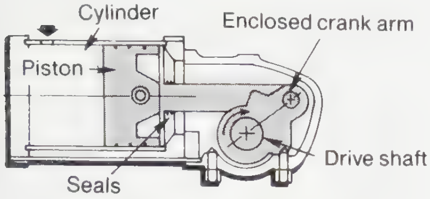
MOSIER

MOSIER INDUSTRIES, INCORPORATED
325 CARR DRIVE / P.O. BOX 189
BROOKVILLE, OHIO 45309
(513) 833-4033 / FAX: (513) 833-4205

Circle 533

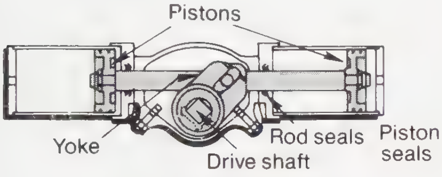
stroke. Stroke is ordinarily adjustable from 85 to 100°.

Fail-safe variations on the basic cylinder are used where a power failure or fluid loss could suspend the controlled object in a dangerous position. Fail-safe actuators are spring-loaded to ensure the return of the shaft to a safe position — they are available with torque outputs to over 5,000 lb-in.



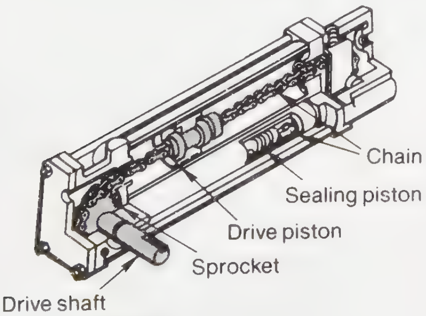
LINEAR CYLINDER ACTUATORS

Scotch yoke actuators provide torque from a linear cylinder mechanism. They can be either single or double acting, producing torque as high as 45 million lb-in., driving through comparatively short arcs — about 90° maximum. Output torque is not constant, but increases as the piston moves away from its center position.



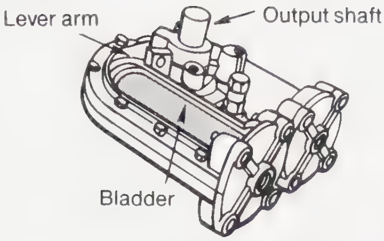
SCOTCH-YOKE ACTUATORS

Sprocket actuators provide long rotations. Up to five complete turns (1,800°) and torques to 23,500 lb-in. are available from sprocket actuators. In these devices, two pistons, a chain, and a sprocket convert fluid pressure into torque. The large piston acts as the driver, pulling the chain. The smaller piston seals against fluid leakage past the return side of the endless chain.



SPROCKET ACTUATORS

Bladder actuators route fluid into rubber bladders that push against a cup-shaped lever arm to provide rotary motion up to 100°. As long as bladders remain intact, there can be no leakage across the lever arm, so the actuators provide excellent angular accuracy. Bladders can be compounded for compatibility with almost any fluid medium, and are insensitive to abrasive particles in the fluid.

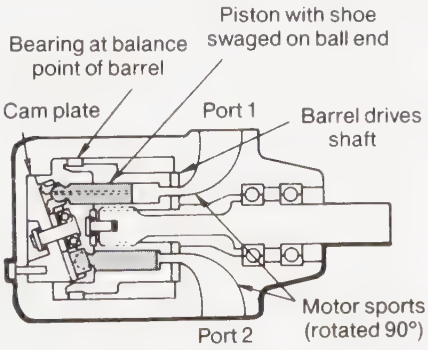


BLADDER ACTUATORS

Fluid motors

Generally, hydraulic and pneumatic motors are organized along similar principles. The internal engineering of each is quite different, but the operating philosophies are very similar.

Axial-piston motors contain several pistons — usually seven to nine — that are extended by high-pressure fluid. The pistons are restrained at one end by an angled plate: As they bear against the plate, they generate a rotating force that may either twist the plate or the barrel in which the pistons are rotated. In most designs, the shaft is driven directly from either the barrel or the cam plate; in a few hydraulic motors, the shaft is driven through a differential-gear arrangement that permits low speed and high torque.


Piston with shoe swaged on ball end
Bearing at balance point of barrel
Cam plate
Port 1
Barrel drives shaft
Motor sports (rotated 90°)
Port 2

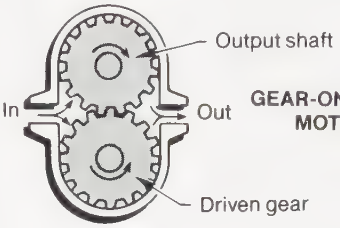
AXIAL-PISTON MOTOR

Axial-piston motors have a reputation for high volumetric efficiency, combined with excellent operation at both high and low speeds. In hydraulic designs, axial-piston motors produce maximum torques to 17,500 lb-in. from pressures to 5,000 psi, generating maximum speeds to around 4,500 rpm.

Pneumatic axial piston motors are available only in the smaller ranges, in sizes to 3 hp. Most axial piston air motors are grease lubricated and require provision for regular servicing.

Radial-piston motors have pistons that radiate out from the drive shaft, and are arrayed in a number of ways. They can produce torques over one million lb-in. at pressures exceeding 5,000 psi. Speeds can range from 0.1 to 2,000 rpm.

Radial-piston air motors are generally limited to free speeds below 4,000 rpm, with design speeds below 2,000 rpm. They provide high starting torque, reliability, and built-in lubrication, but are not normally governed.

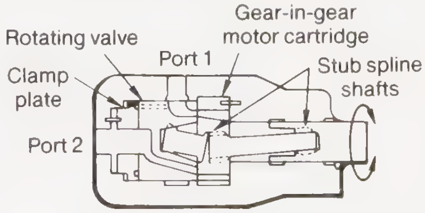


GEAR-ON-GEAR MOTOR

Gear-on-gear motors are the most common hydraulic units. They consist of a pair of matched spur or helical gears enclosed in a case. These units develop maximum torques of about 6,000 lb-in., accepting inlet pressures to 3,000 psi and operating to 3,000 rpm.

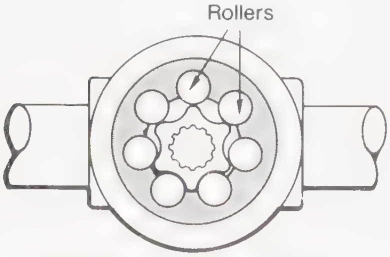
Gear-within-gear motors, often called gerotors, are very compact for their displacement. The inner gear seals against the outer to guard against fluid leakage. Tooth velocities and wear are low and power density is high. Gear-within-gear motors can accept pressures to 2,000 psi and deliver torques to 1,500 lb-in. at speed ranges to over 5,000 rpm. Gerotor air motors function similarly to their hydraulic counterparts, but are designed for low-speed operation, generally under 200 rpm.

Differential gear motors are a variation of the gerotor type, developed to produce high torque at low speed. The outer gear is held fixed, and the inner gear is allowed to orbit within it. A stub spline shaft, with eccentric action at both ends, connects the inner gear to the output shaft. Operating at pressures to 1,500 psi, these motors deliver torques to 3,700 lb-in. at speeds to 1,000 rpm.



DIFFERENTIAL-GEAR MOTOR

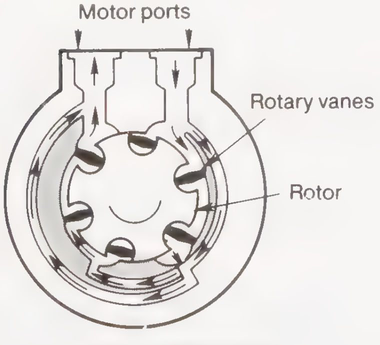
Roller-gerotor motors are a variation on gerotor differential-gear motors. Lobes of the outer gear are replaced by rollers that reduce friction. Thus, the motors tend to have higher efficiencies, lower starting torques, and longer lives. These motors accept pressures up to 4,500 psi and produce torques to 16,400 lb-in., and speeds to 850 rpm.



ROLLER-GEROTOR MOTOR

Crescent gear motors have a small gear within a larger one, with a fixed crescent-shaped element between the gears. The gear teeth seal against the crescent. These motors produce speeds to 5,000 rpm, operating on maximum pressures of 500 psi.

Vane motors are used for both pneumatic and hydraulic operation. (In reality, the same motor is rarely suitable for operation on both hydraulic fluid and air, but the principle of vane operation is equally acceptable.)



AXIAL-VANE MOTOR

In both hydraulic and pneumatic versions, vane motors consist of a slotted rotor mounted eccentrically within a circuit cam ring. Vanes in the rotor slots are free to move in and out; they are often spring-loaded to the outward position. As air or fluid enters the motor, it applies force against the vane, turning the rotor and allowing the fluid to sweep from inlet to outlet ports.

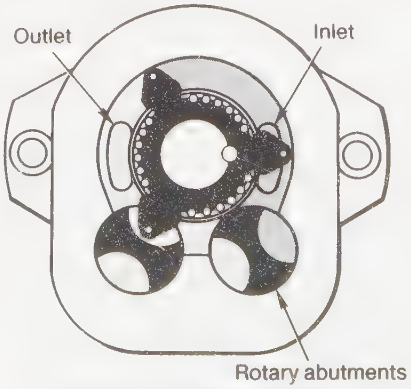
Most hydraulic vane motors use a two or four-port configuration so that the fluid passes in one side of the vane and out the other, or passes in and out through two ports on each side of the vane. In the latter configuration, each vane provides torque to the rotor twice each revolution. The torque of a four-port motor is twice that of a similarly sized two-port motor, and speed is approximately half. A few vane motors for hydraulic applications use even more ports to create a high-torque, low-speed motor.

For normal units, with only two inlet ports, maximum torque is 4,000 lb-in. at maximum continuous pressures of about 2,500 psi. Top speed is 4,000 rpm.

Vane motors for pneumatic systems operate at free speeds to 13,000 rpm, with rated speed approximately 50% of that level. Torques well in excess of 2,000 lb-in. are available at rated operating pressures of 90 psi. These pneumatic vane motors must be provided with some method for feeding lubricant into the air stream because the outer ends of the vanes rub against the cylinder wall. They also typically require a governor to inhibit operation at free speed. An ungoverned vane motor, allowed to reach free speed, may damage itself or connected machinery.

Axial-vane motors use vanes that rotate instead of sweeping in and out to seal. These motors may have very small fixed clearances and low stalled friction for excellent low-speed capability. Unlike conventional vane motors, they cannot compensate for wear so they require good filtration for continued trouble-free service. They deliver torques to 3,200 lb-in., at continuous pressures to 2,000 psi, with continuous speeds in the range of 5 to 1,500 rpm.

Rotary abutment motors are hydraulic units that consist of a three-lobe rotor, with each lobe carrying a roller in a dovetail groove. The rollers provide a positive seal between the rotor and housing. The sealing arrangement is substantially frictionless and relatively insensitive to wear. The motor contains two rotary abutments, one of which rotates to pass a rotor lobe while the second seals the rotor hub. Timing gears between the output shaft and rotary abutments keep the rotor and abutments in proper phase. The motors provide continuous running torques as high as 3,200 lb-in. at continuous pressures of 2,000 psi. Maximum speed range is 650 to 1,400 rpm.



ROTARY ABUTMENT MOTOR

Turbine motors, used exclusively in pneumatic systems, can be either single or multistage units. They can be driven by a wide variety of gases and vapors such as compressed air, natural gas, nitrogen, steam, and the Freons. Because turbine motors fully expand the compressed gas and have very low frictional losses, they are the most efficient type of pneumatic motor for integral-horsepower applications. Because the motors have no rubbing surfaces as in vane motors, no lubrication is required in the drive gas. Turbine motors are available with power ratings from fractional horsepower to 85 shaft hp at drive pressures to 90 psig. They also are available with or without gear reducers to provide a range of speeds from 0 to 25,000 rpm. Units without gear reducers typically weigh from 3 to 20 lb.

Hydrostatic drives

Hydrostatic drives are widely recognized as an excellent means of power transmission when variable output speed is required. Typically outperforming mechanical and electrical variable-speed drives and gear-type transmissions, they offer fast response, maintain precise speed under varying loads, and allow infinitely variable speed control from zero to maximum.

Unlike gear transmissions, hydrostatics have a continuous power curve without peaks and valleys, and they can increase available torque without shifting gears. But despite the superior performance of hydrostatics, a major drawback has been higher cost compared to their mechanical counterparts.

Manufacturers, however, continue to boost performance levels, produce smaller and lighter packages, and offer advanced electronic controls. These factors now make hydrostatics an economical choice for many applications.

A basic hydrostatic transmission is an entire hydraulic system. It contains pump, motor, and all required controls in one simple package. Such a system provides all the noted advantages of a conventional hydraulic system — such as stepless adjustment of speed, torque, and power; plus smooth and controllable acceleration; ability to be stalled without damage; and easy controllability — with the convenience of single-package procurement installation.

Early hydrostatic transmissions were intended primarily for low-cost applications such as farm equipment and garden tractors. But improved de-

New Parker XL Series Linear Slides…

Reduce set-up time, offer greater versatility

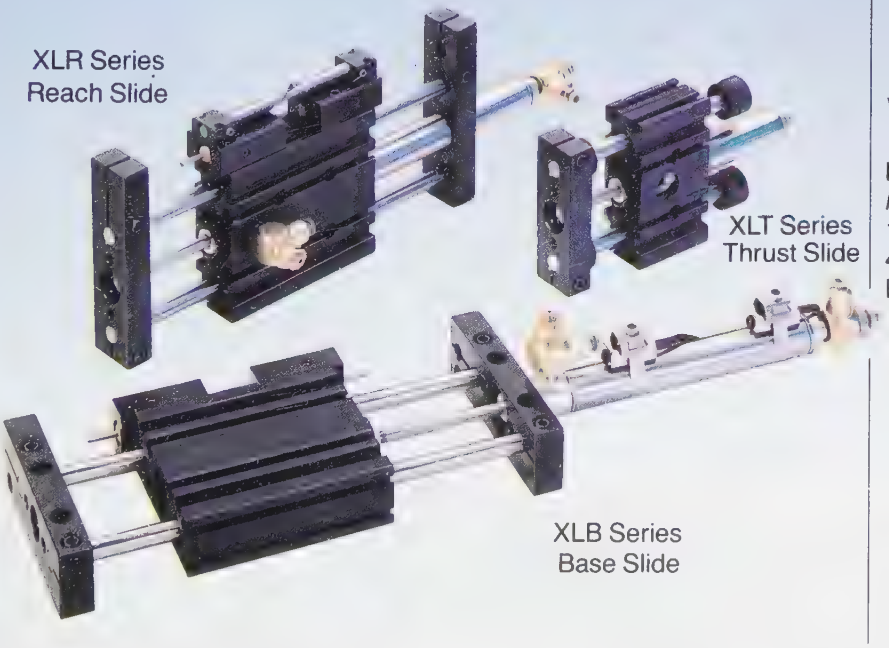
Our innovative square-nut "T-slot" concept makes true component modularity possible — for the first time.

Powered by a pneumatic cylinder, XL Series Slides deliver accurate, torque-resistant linear motion by combining a pair of precision ground Rc 60-65 case-hardened support shafts and four recirculating ball bearing bushings. The bearings and cylinder are pre-lubricated to provide millions of non-lube, trouble-free cycles.

The heart of it all.
The core element of the Parker XL Series is the revolutionary T-slot extruded aluminum housing which facilitates component assembly and accurate attachment without time-consuming drilling and tapping to reduce cost and time.

Building-block modularity.
Totally compatible transition plates make possible an easy building-block approach to the assembly and installation of any related Parker automation component. We offer a full line of options and accessories for our new XL Series to meet your needs.

Broad range of applications.
Some of the many uses for the new Parker XL Series Linear Slides are material handling, packaging, product testing, assembly, pick-and-place operations, parts transfer, machine loading and unloading, clamping, and other automation operations.



Three types available. Support rod sizes: ¼,″ ⅜,″ ½,″ and ¾″.

- Parker XLT Series Thrust Slides provide thrust for lighter loads, shorter strokes, and vertical applications.
- Parker XLR Series Reach Slides provide reach for heavier loads, longer strokes, and horizontal applications.
- Parker XLB Series Base Slides with moving body and stationary end plates, for material transfer applications.

Contact Parker — now!
Our worldwide network of Parker distributors is ready to help you select the appropriate T-slot linear slide for your particular application. And we offer a wealth of technical expertise, product information, competitive pricing, quick turnaround, and in-stock parts and accessories.

Write, fax, or call us today for our free catalog.

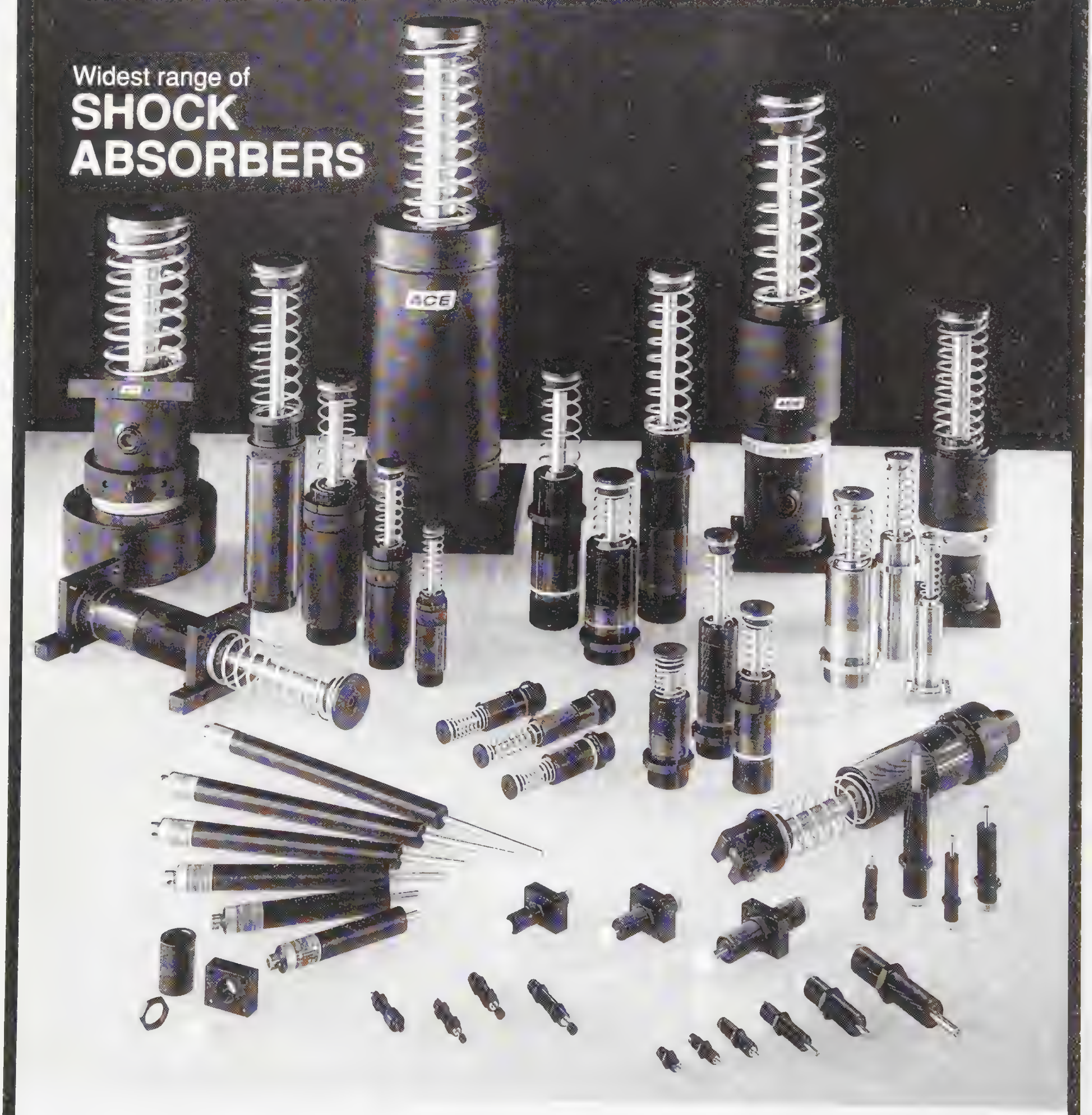
Parker Hannifin Corporation,
Rotary Actuator Division,
135 Quadral Drive, Wadsworth, OH 44281. Phone: 216-336-3511.
FAX: 216-334-3335.

Worldclass Quality Products and Service

Parker
Fluidpower

Circle 534

ACE controls inc.
World leader in deceleration technology

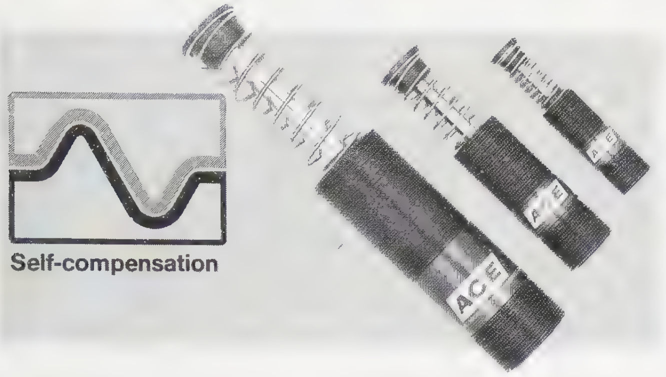


Widest range of
SHOCK
ABSORBERS

- The world's most recognized line of industrial shock absorbers
- The industry's most responsive technical support staff
- State-of-the-art technology - CAD/CAM/CAS
- Highest quality, best value
- Widest range of energy capacities
- Lifetime warranty
- Worldwide distribution
- Off-the-shelf delivery

23435 Industrial Park Dr. • P. O. Box 71 • Farmington, MI 48332-0071
(313) 476-0213 • 1(800) 521-3320 • FAX (313) 476-2470

From ACE...another breakthrough in DECELERATION TECHNOLOGY

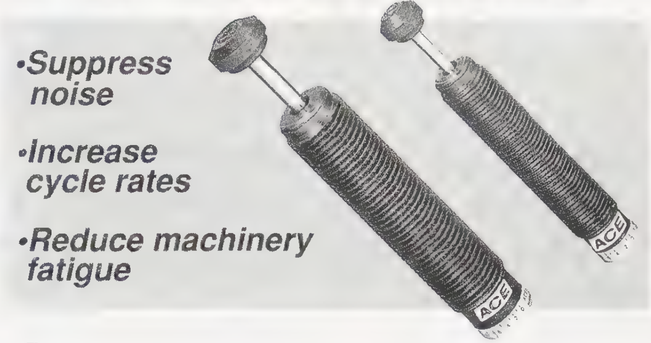


New MC Series 1200, 1400 and 1600 models, in stroke lengths from 1 in. to 6 in., offer incomparable design flexibility. Threaded bodies and a complete range of mounting accessories allow ease of installation. Computer-designed, self-compensating orificing provides smooth deceleration without adjustment through a wide range of effective weights and energy capacities from 900 to 30,000 in.-lbs. per cycle.

Advancing the state of the art, **ACE Controls, Inc., Box 71, Farmington, MI 48332-0071. (313) 476-0213 or (800) 521-3320.**

Circle 671

New miniature linear decelerators STOP LOADS SAFELY



Decelerate loads, prevent impact damage, dampen noise and improve product performance with ACE shock absorbers. The miniature, adjustable MA Series provides true linear deceleration for smooth, quiet stops. Use with packaging machinery, robotics, material handling equipment or anywhere motion control is desired. New 3/4" and 1" stroke models offer twice the capacity of comparable units. Fully threaded bodies feature easy installation, lockable adjustment, integral mechanical stop and lifetime warranty. Call for free catalog.

Advancing the state of the art, **ACE Controls, Inc., Box 71, Farmington, MI 48332-0071. (313) 476-0213 or (800) 521-3320. Fax (313) 476-2470.**

Circle 672

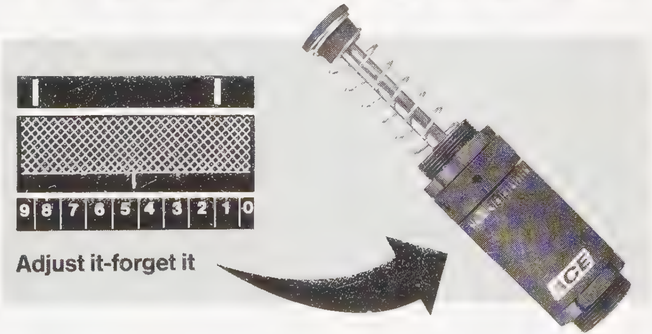
ACE's new software program solves SHOCK PROBLEMS

ACE shock absorbers decelerate loads, prevent impact damage and improve product performance. New ACE computer assisted design and computer assisted selection software makes it easier to design in and choose the right shock absorber for your application. Create CAD files in AutoCad, DXF and IGES file formats. CAS program uses weight, velocity and force data to calculate shock selection. Call for free catalog describing the world's widest range of shock absorbers.

Advancing the state of the art, **ACE Controls, Inc., Box 71, Farmington, MI 48332-0071. (313) 476-0213 or (800) 521-3320. Fax (313) 476-2470.**

Circle 673

Control impact damage with ACE's ADJUST-A-SHOCK



Stop moving loads quickly, safely and quietly with ACE Primary Series shock absorbers. Adjustable feature allows you to custom 'tune-in' the shock to meet your application's precise requirements. Only ACE calibrates every shock, providing the most accurate deceleration in the industry.

The versatile Primary Series offers three bore sizes and eight stroke lengths. Unlimited mounting options, off-the-shelf delivery. ACE's shock absorber line is the widest in the world, with capacities from under one in.-lb. to over 6 million in.-lbs. per cycle. Advancing the state of the art, **ACE Controls, Inc., Box 71, Farmington, MI 48332-0071. (313) 476-0213 or (800) 521-3320.**

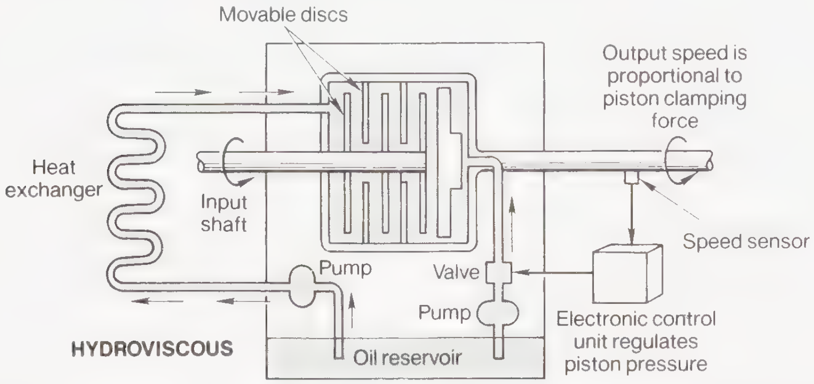
Circle 674

ACE controls inc.

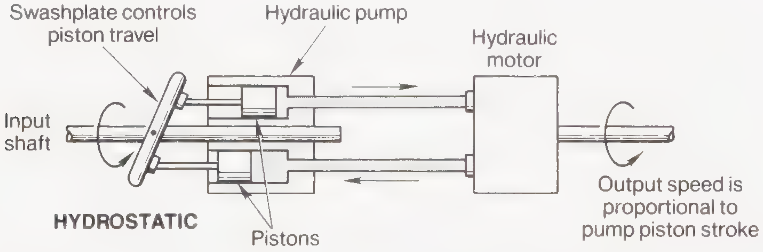
World leader in deceleration technology

ADJUSTABLE-SPEED FLUID DRIVES

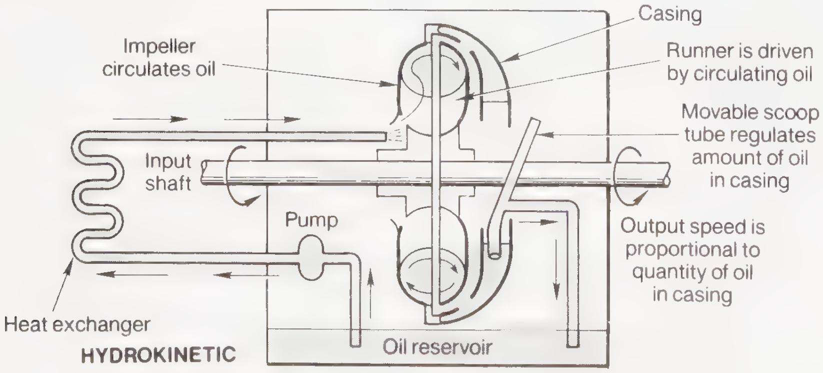
Hydroviscous drive contains oil between multiple discs coupled to the input and output shafts. An electronic control unit provides a feedback signal that actuates a piston and varies the clamping force against the discs to control slip rate. Slippage produces waste heat dissipated by a heat exchanger.


Movable discs
Output speed is proportional to piston clamping force
Heat exchanger
Input shaft
Speed sensor
Pump
Valve
Pump
Electronic control unit regulates piston pressure
HYDROVISCOUS
Oil reservoir

Hydrostatic drive consists of a hydraulic pump and motor system. Input-to-output speed ratio is regulated by a swashplate that controls piston travel in the pump. Output speed of the hydraulic motor is a direct function of its displacement and volume of fluid delivered to it by the pump.


Swashplate controls piston travel
Hydraulic pump
Hydraulic motor
Input shaft
HYDROSTATIC
Pistons
Output speed is proportional to pump piston stroke

Hydrokinetic drive transmits power through a vortex of hydraulic oil. Oil is accelerated by an impeller, and the circulating fluid drives a runner. Output speed is regulated by adjusting the quantity of the oil in the casing with a movable scoop tube.


Casing
Impeller circulates oil
Runner is driven by circulating oil
Movable scoop tube regulates amount of oil in casing
Input shaft
Pump
Output speed is proportional to quantity of oil in casing
Heat exchanger
HYDROKINETIC
Oil reservoir

signs — particularly in controls — have made these transmissions suitable for a broad range of applications.

As a result, light-duty units (less than 20 hp) are being used on equipment such as lawn tractors, golf-course maintenance equipment, and small machine tools; medium-duty units (25 to 50 hp) on skid-steer loaders, trenchers, harvesters, and other such vehicles; and heavy-duty transmissions (approximately 60 hp and higher) on agricultural and large construction equipment.

Part of the reason for the increasing attractiveness of hydrostatic transmissions is improved design of pumps and motors — particularly higher flow and pressure ratings in a more compact package. For example, several years ago, most pumps could be expected to deliver about 0.125-gpm flow per pound of pump. Currently available pumps deliver about 0.5 gpm/lb, a 400% increase. Similarly, older motors provided about 0.5 hp/lb of motor; new motors provide about 2.5 hp/lb.

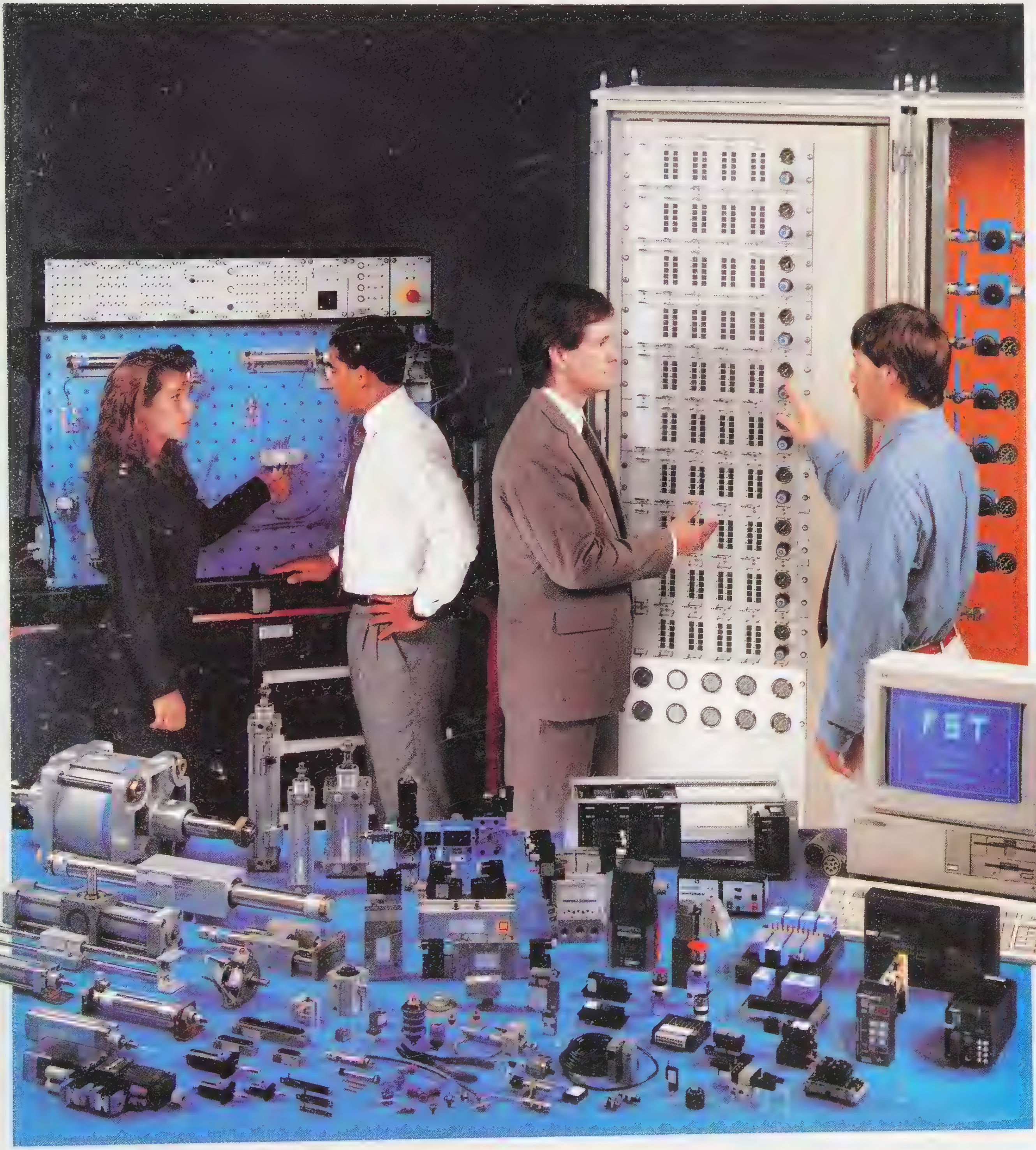
Performance: Hydrostatic transmissions are commonly available with at least three standards of output performance:

- Variable-power, variable-torque transmissions are based on a variable-displacement pump supplying a variable-displacement motor. They can provide a combination of constant torque and constant power. These units are adjustable, flexible, and expensive.
- Constant-torque, variable-power transmissions are based on a variable-displacement pump supplying fluid to a fixed-displacement motor under constant load. Speed is controlled by varying pump delivery. This is considered the best general-purpose drive, with wide speed ranges, up to 42:1, and simple controls.
- Constant-power, variable-torque transmissions are based on a variable-displacement pump with a power limiter, driving a fixed-displacement motor. The forte of this unit is efficiency, but speed range is usually limited to 4:1.

Drive configurations: Hydrostatic transmissions usually take one of two general configurations, split or close coupled. A split transmission consists of a power unit with the hydraulic pump, heat exchanger, filters, valves, and controls mounted on a reservoir. The hydraulic motor is remotely mounted and connected to the power unit through hose or tubing. Split transmissions are typically used in heavy-duty applications because they offer wide flexibility in configuring a system for the most efficient use of space or best weight distribution.

Integrated, or close-coupled, transmissions have a hydraulic pump and motor that share a common valving surface. This arrangement provides an extremely short oil-flow path, eliminating high-pressure oil leaks either to the reservoir or to the environment. A cast casing or housing provides a self-contained oil reservoir, structural support for the rotating elements, and heat dissipation. They are usually bolted directly to a mechanical differential axle to form a hydrostatic transaxle. Close-coupled transmissions are typically found in light-duty applications, where tight space constraints require compact units, while high-volume production mandates easy assembly.

Festo...Your Single-Source Resource
For Intelligent Automation Solutions



FESTO

Circle 535

Automation is key for growth in the 1990's! And Festo has the resources and experience you need...

From Intelligent Components and Controls...to complete Control Systems, Education & Training...Intelligent Automation Solutions from Festo will help you meet the challenge of the future!

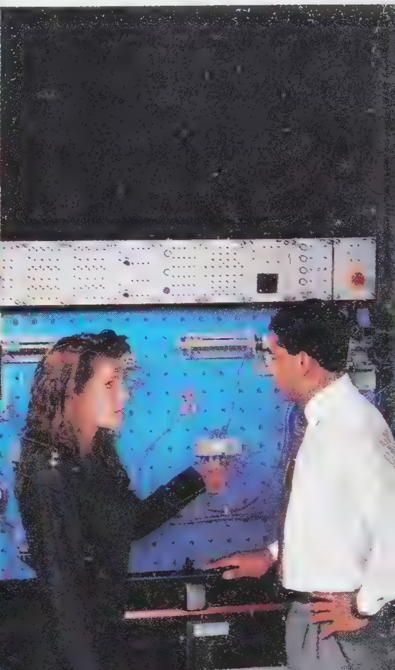
Intelligent Automation Starts with People...

Give your people the knowledge and skills they need to operate and maintain the automated systems your plant relies on.

The Festo Learning System is a hands-on approach designed to produce performance improvements immediately.

From simply sending a technician to one of our courses...to designing a training center in your plant, Festo has been the choice for over 30 years. Curriculum, courses and hardware encompass:

FESTO
DIDACTIC



- **Pneumatics**
- **Electro-Pneumatics**
- **Hydraulics**
- **Electro-Hydraulics**
- **Proportional-Hydraulics**
- **Programmable Controllers**
- **Digital Electronics**
- **Automation Systems**
- **CIM, Computer Integrated Manufacturing**

Intelligent Components "Close the loop"...

A leader in merging pneumatics and electronics, Festo is known around the world for innovative design solutions for automation.

Festo now offers more intelligent components with sensing capability to "close the loop" in today's integrated systems...

From Micro-Pneumatics and proportional valves to fiber-optic sensors...Festo's comprehensive product range encompasses over 4,000 products:

FESTO
PNEUMATIC

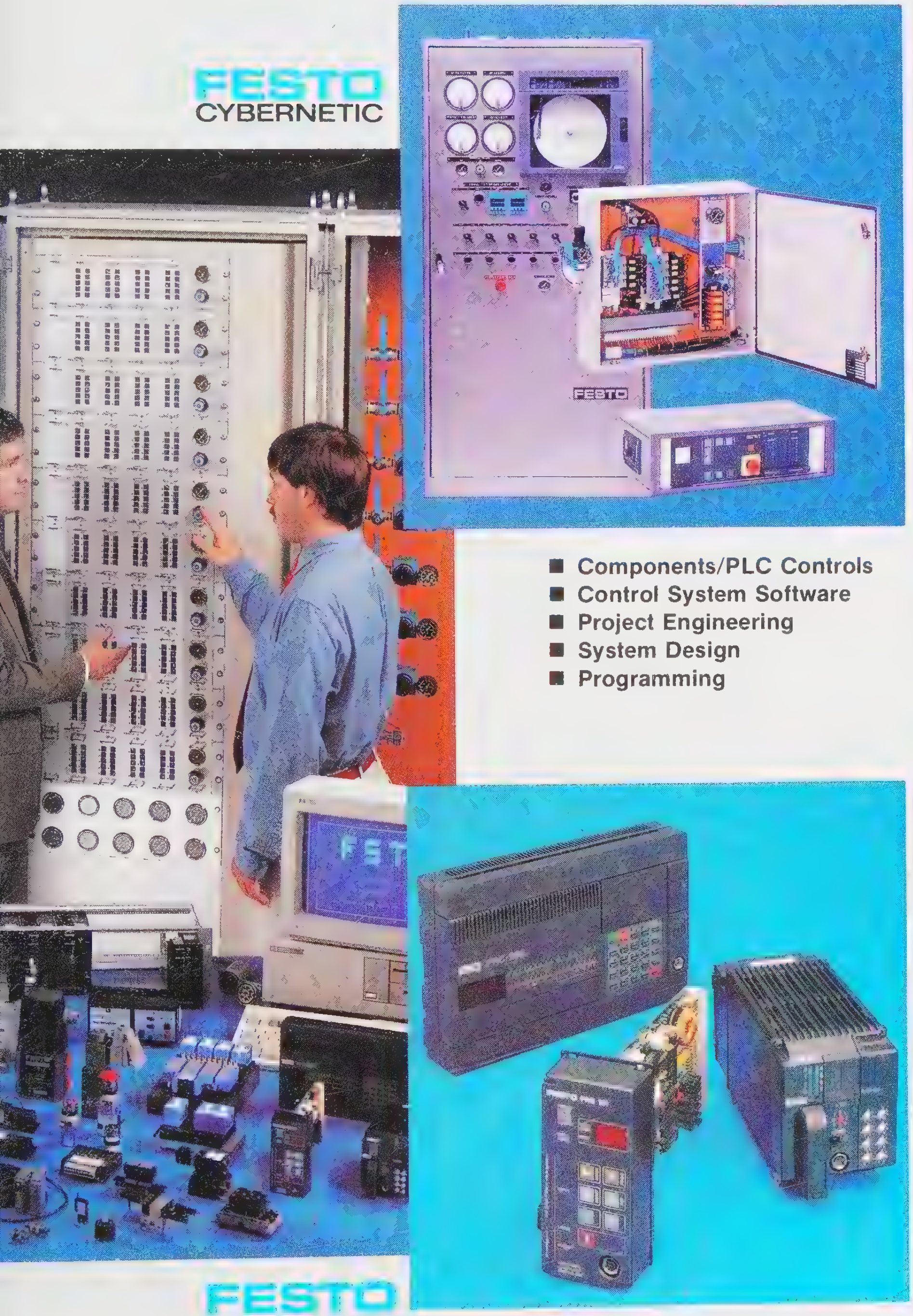
- **Pneumatic Controls**
- **Pneumatic Cylinders/Valves**
- **Sensors & E/P Interfaces**
- **Vacuum Components**
- **Index Tables & Feed Units**
- **FRLs, Fittings & Accessories**

© 1989 Festo Corporation

When you think Automation... Think Festo!

> “Companies who know us say
> our products and people
> are the best in the world...”

FESTO
CYBERNETIC



Intelligent Automation System Solutions...

Festo Cybernetic integrates the building blocks of automation... processors, actuators and sensors, into an intelligent system solution, packaged to meet your specifications.

Whether your control needs are simple or sophisticated, Festo offers you more flexibility and options, ranging from providing small pre-engineered control cabinets, to design and delivery of large, custom engineered systems, complete with external actuators and sensing devices:

- **Components/PLC Controls**
- **Control System Software**
- **Project Engineering**
- **System Design**
- **Programming**
- **Cabinet Construction**
- **Testing**
- **Delivery**
- **Post-Installation Service**

FESTO
ELECTRONIC

Intelligent Automation Control Solutions...

Festo Electronic programmable logic controllers provide the user-friendly, intelligent solution for meeting the increasing demand for 'flexible' manufacturing and production in small, medium and multi-level automation applications.

The field-proven, modular design of the "FPC" Series PLCs enables you to adapt the control to meet the project size, complexity and speed you need, now and in the future, as your requirements grow.

- **Festo “FST” software turns your IBM-PC XT/AT* compatible computer into a versitile programming and documentation center**
- **User-friendly interfaces**
- **Off-line programming versatility**
- **On-line diagnostics capability reduces down-time**
- **Multiple programming languages**

*IBM and IBM PC/XT/AT are registered trademarks of International Business Machines Corporation

Circle 535

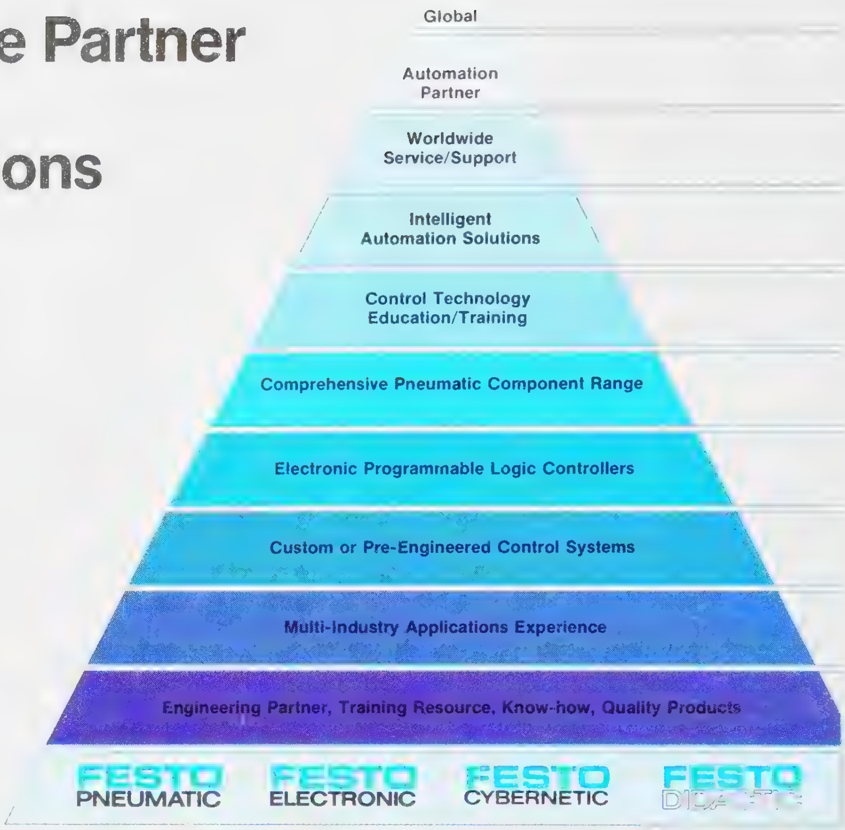
Festo...
Your Single Source Partner for Intelligent Automation Solutions

If you're looking for a dependable resource to help automate your plant or factory, Festo is the right partner for you!

With its 30+ years of worldwide experience serving virtually every industry, Festo has the engineering expertise, the broad product range and the educational resources to serve you as a reliable, single-source partner for intelligent, low-cost automation solutions.

Festo's pyramid of options provides the flexibility you need to automate intelligently, according to your company's requirements.

Contact the Festo Regional Center or branch office nearest you to put Festo on your team for increased productivity and profits through intelligent automation.


Global

Automation Partner

Worldwide Service/Support

Intelligent Automation Solutions

Control Technology Education/Training

Comprehensive Pneumatic Component Range

Electronic Programmable Logic Controllers

Custom or Pre-Engineered Control Systems

Multi-Industry Applications Experience

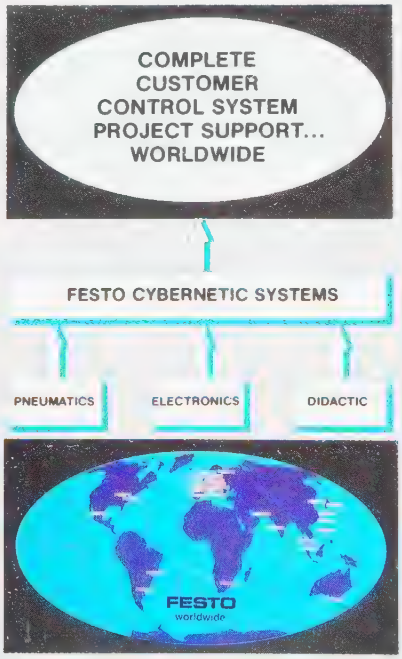
Engineering Partner, Training Resource, Know-how, Quality Products

FESTO PNEUMATIC

FESTO ELECTRONIC

FESTO CYBERNETIC

FESTO DIDACTIC

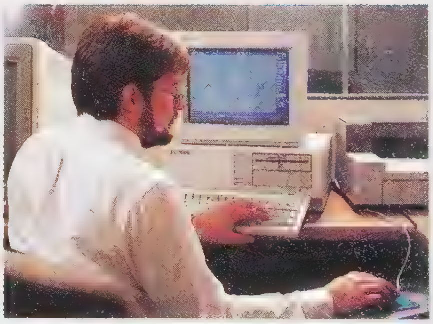

COMPLETE CUSTOMER CONTROL SYSTEM PROJECT SUPPORT... WORLDWIDE

FESTO CYBERNETIC SYSTEMS

PNEUMATICS

ELECTRONICS

DIDACTIC



FESTO

NEW YORK	(516) 435-0800	FAX: (516) 435-0581
BOSTON	(617) 245-4111	FAX: (617) 245-8999
CHARLOTTE	(704) 527-1427	FAX: (704) 527-7935
CHICAGO	(708) 810-0135	FAX: (708) 810-0814
DETROIT	(313) 585-1388	FAX: (313) 585-1582
MILWAUKEE	(414) 783-3555	FAX: (414) 783-3540
DALLAS	(214) 341-9477	FAX: (214) 553-1126
LOS ANGELES	(714) 757-0777	FAX: (714) 757-0660
SAN JOSE	(408) 432-0380	FAX: (408) 432-0983

FESTO CORPORATION: 395 MORELAND ROAD, HAUPPAUGE, N. Y. 11788 • (516) 435-0800 • TELEX: 96-8399 • FAX: 516-435-8026
FESTO INC., 215 CARLINGVIEW DR., REXDALE (Toronto) ONTARIO, M9W 5X8 • (416) 675-2090 • FAX: 416-675-2055

Circle 535

Transmission sizing: Hydrostatic transmission size normally is based on the corner horsepower of the work function. Corner horsepower is the product of the maximum force and maximum speed required by the function, even though these two conditions rarely occur simultaneously. Corner horsepower for vehicle propulsion is

$$H_c = \frac{F_t V}{3{,}600\eta}$$

where H_c = corner horsepower, kW; F_t = maximum vehicle tractive force, N; V = maximum vehicle speed, km/h; and η = final drive efficiency, %.

Transmission corner horsepower, H_t, is the product of maximum output torque (generally at a specified maximum pressure) and maximum output speed:

$$H_t = \frac{T_\tau N}{9{,}550}$$

where T = theoretical torque at maximum system pressure, N-m; τ = torque efficiency, %; and N = maximum transmission speed, rpm.

Initial transmission selection is made by comparing the results of these calculations. Selection is refined by considering the effects of duty cycle, final-drive ratio, rolling radius, primer-mover speed, and design life.

Electronic controls: Control capabilities for hydrostatic transmissions have advanced from simple remote electrical actuators to packages that offer complete optimization of machine performance. For example, electronics on paving equipment not only controls the transmission, including speed and rate of acceleration and deceleration, but also steering, paving height, rate of material flow, road crown, slope on curves, and so on.

While not currently economical for every application, proportional controls offer a reasonable payback in most traction drives and propel systems through fuel savings and increased productivity. Acceptance will quicken when the added benefits in addition to primary control are recognized. One such feature is performance monitoring, another is system diagnostics — relating when servicing is needed, when failure is imminent, or where a failure has occurred. Such features are relatively easy to add into software because many of the variables needed are already measured for control.

Hydrokinetic

Hydrokinetic drives are typically rated from 1 to 5,000 hp but higher ratings are common. Largest units are rated at 25,000 to 30,000 hp.

Because there is no mechanical lockup between the driver and driven elements, the drive has a constant 2 to 4% slip that, although reducing efficiency, provides good shock protection to the driven and the driving equipment.

To remove heat generated by this slippage, all hydrokinetic drives require a heat exchanger. However, constant-speed hydrokinetic couplings used for soft starts are totally self-contained and do not need heat exchangers. Only variable-speed hydrokinetic couplings are equipped with heat exchangers.

These drives are controlled by adjusting the amount of oil in the casing. Most scoop-tube controlled hydrokinetic drives use electrical, hydraulic, or pneumatic controllers, but a few drives are manually controlled.

Because the drive operates by the impeller input circulating the oil, the hydrokinetic drive is particularly vulnerable to inaccuracies at low speeds. Thus, minimum output speeds are usually specified. The minimum output speed at which the drive will continuously operate is given usually in terms of a percent of input speed. Operation below this minimum ordinarily is not permissible except in the transient conditions of clutching and declutching. These minimum output speeds are typically 20 to 30% of input speed for variable torque loads and 35 to 45% for constant-torque loads.

In theory, maximum torque is transmitted at 100% slip when the turbine is stalled and the impeller turns at motor speed. However, in a standard constant-speed hydrokinetic fluid coupling, maximum torque is not exactly at 0% output speed. Maximum torque occurs at about 10% slip. This can be significant and must be considered if a fluid coupling is used as a torque limiter in a power train. Recent developments in fluid couplings allow some to produce soft starts and low torque limits.

Torque limitation can be as low as 130% but normally is about 150%. Without the soft-start feature, fluid couplings can only offer torque limitations of 170 to 180%, usually too high for material-handling equipment.

Studies from power utilities suggest that for large power transmission, hydrokinetic fluid drives require less maintenance than hydrostatic or hydroviscous types. This is because a fluid, rather than a solid surface, transmits power from impeller to turbine.

Typical applications include conveyor drives, to provide smooth starts and minimize belt stretch; on diesel engines, to protect gearboxes from torque fluctuations; and on automatic transmissions.

Hydroviscous

Hydroviscous drives use the viscous property of fluid to develop drive torque. Basically, a shearing action can be developed in fluid between adjacent rotating disks, making it possible to transmit torque from one disk to another.

Hydroviscous drives are the only fluid drives providing full lockup at full-speed operation. They are rated from 5 to 20,000 hp at 1,800 rpm and are often used in high-inertia, high-power applications. Below 25 hp, this type of drive tends to be more costly than comparable belt or chain drives. But hydroviscous drives offer greater speed ratios (to 20:1).

All hydroviscous units must have a heat exchanger. Also, all hydroviscous drives must be controlled by either open-loop or servocontrol closed-loop circuits.

Typical applications include cycling drives on stamping presses and packaging machines; constant-tension drives and dynamometers; adjustable-speed drives; and as couplings in high-hp applications.

Shock absorbers

A number of different shock absorber designs are available, but the fundamental operation of each is the same. Shocks are basically multiple-chambered cylinders, with one or more orifices between chambers. As an object strikes the cylinder rod, an internal piston moves, increasing fluid pressure in the cylinder. Fluid flows through the orifices, dropping in pressure and increasing in temperature. Thus, the kinetic energy of a moving object is converted to heat as it is stopped.

Efficiency and effectiveness of the absorber depend almost entirely on the leakage path between the two sides of the cylinder. But energy-absorbing capacity depends on the size of the shock absorber and the method of returning the piston to its rest position.

Spring-return shock absorbers are more compact and convenient than external-accumulator models, but do not have as much energy capacity. Accumulator shock absorbers have more hydraulic fluid and more surface area from which to radiate heat. Therefore, they can be cycled more frequently at maximum capacity than spring-return models.

Hydroshocks are nonadjustable, multiple-orifice devices, with holes spaced along the length of a cylinder. When a hydroshock is loaded, an internal piston moves along the cylinder, closing the holes one at a time and decreasing the effective orifice area. Orifice size and spacing are critical and best accomplished by sophisticated computer modeling. Otherwise, proper orificing could take several months of hand calculations and testing.

The hydroshocks main advantage is its nearly perfect deceleration while its chief advantage is that it only works for one weight, velocity, and propelling force. If the shock is not properly sized for the application, the result is high collision or set-down forces.

Adjustable shock absorbers feature a series of orifice holes machined along the length of a fixed metal tube. A slotted metering tube, which fits over the stationary tube, can be rotated via an external ring to adjust total effective area and desired deceleration rate. When the metering tube is rotated toward the open position, the shock provides maximum orifice area and minimum resistance. Conversely, movement toward the closed position reduces orifice area and increases resistance. This adjustment method gives the capability to handle large weights or high propelling forces at low viscosities.

Adjustable shocks overcome the chief disadvantage of the hydroshock by adjusting the orificing to custom fit any input conditions. Therefore, a properly adjusted shock can produce the same nearly perfect deceleration as a hydroshock.

The shock's main advantage is the ability to handle a wide range of input conditions; it's chief disadvantage is that it must be manually adjusted each time the input condition changes.

Self-compensating shocks are fixed-orifice devices which require no adjustment, and cover a portion of an adjustable model's weight range. Self-compensating shocks decelerate moving weights smoothly, regardless of changes in energy-absorbing requirements, and they also have the tamperproof features of hydroshocks. In reality, self-compensating shocks exhibit minor variations in reaction force with variations in weights and velocities. These forces will be slightly higher than a properly tuned adjustable shock, but still well within acceptable limits.

One important difference, however, is that a single, self-compensating shock cannot cover the full effective weight range of an adjustable shock. For instance, an adjustable shock may handle a very large weight range of 10 to 10,000 lb, while a self-compensating model may be limited to weights of 200 to 1,000 lb. Most users find this range acceptable since the ratio of maximum to minimum weight is rarely more than 5 to 1.

Unlike hydroshocks, self-compensating units do not have a uniform orifice diameter. Rather, the size and location of each orifice is designed for a predetermined range of initial conditions. Such designs compensate for changing weight, velocity, temperature, and fluid compressibility. ■

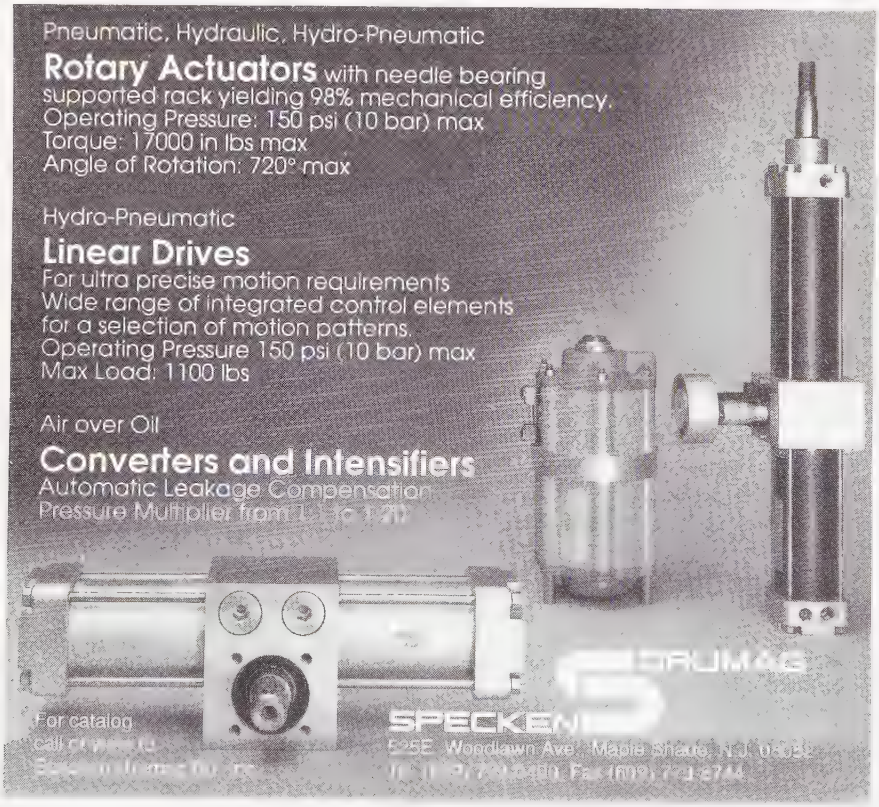
DASHPOTS VS. SHOCKS

While dashpots and shock absorbers both dissipate energy as heat, fill some of the same applications, and are sometimes mistaken for each other, they are two totally different units. In dashpots, force is proportional to velocity, and damping rate remains constant throughout travel. In shock absorbers, force is usually proportional to velocity squared, and resistance builds to a required level and is maintained for virtually the entire displacement distance, decreasing as the object comes to rest.

Sealed rotary dashpots give precise control. These units contain a silicone-based fluid to minimize temperature effects, and are filled under vacuum to eliminate entrained air, ensuring predictable damping rate and repeatable performance. Sealing also prevents problems with contamination.

Vane dashpots are one type of sealed dashpot. A vane attached to a shaft moves between fixed vanes on the body, displacing fluid from one side of the rotating vane to the other. Combinations of clearances and fluid viscosities enable variations in the damping rate from one model to another. Vane dashpots have greater damping ability than continuous rotation dashpots. They also cost less and are smaller per unit of damping rate.

Continuous rotation dashpots provide resistance or torque by the shearing of silicone fluid between a multigrooved rotor and stator. The various viscosities of fluid available, combined with the difference in speed between rotor and stator, determine the resistance available. Advantages include virtually unlimited travel and a damping rate that increases as angular velocity increases.


Pneumatic, Hydraulic, Hydro-Pneumatic
Rotary Actuators with needle bearing supported rack yielding 98% mechanical efficiency.
Operating Pressure: 150 psi (10 bar) max
Torque: 17000 in lbs max
Angle of Rotation: 720° max

Hydro-Pneumatic
Linear Drives
For ultra precise motion requirements
Wide range of integrated control elements for a selection of motion patterns.
Operating Pressure 150 psi (10 bar) max
Max Load: 1100 lbs

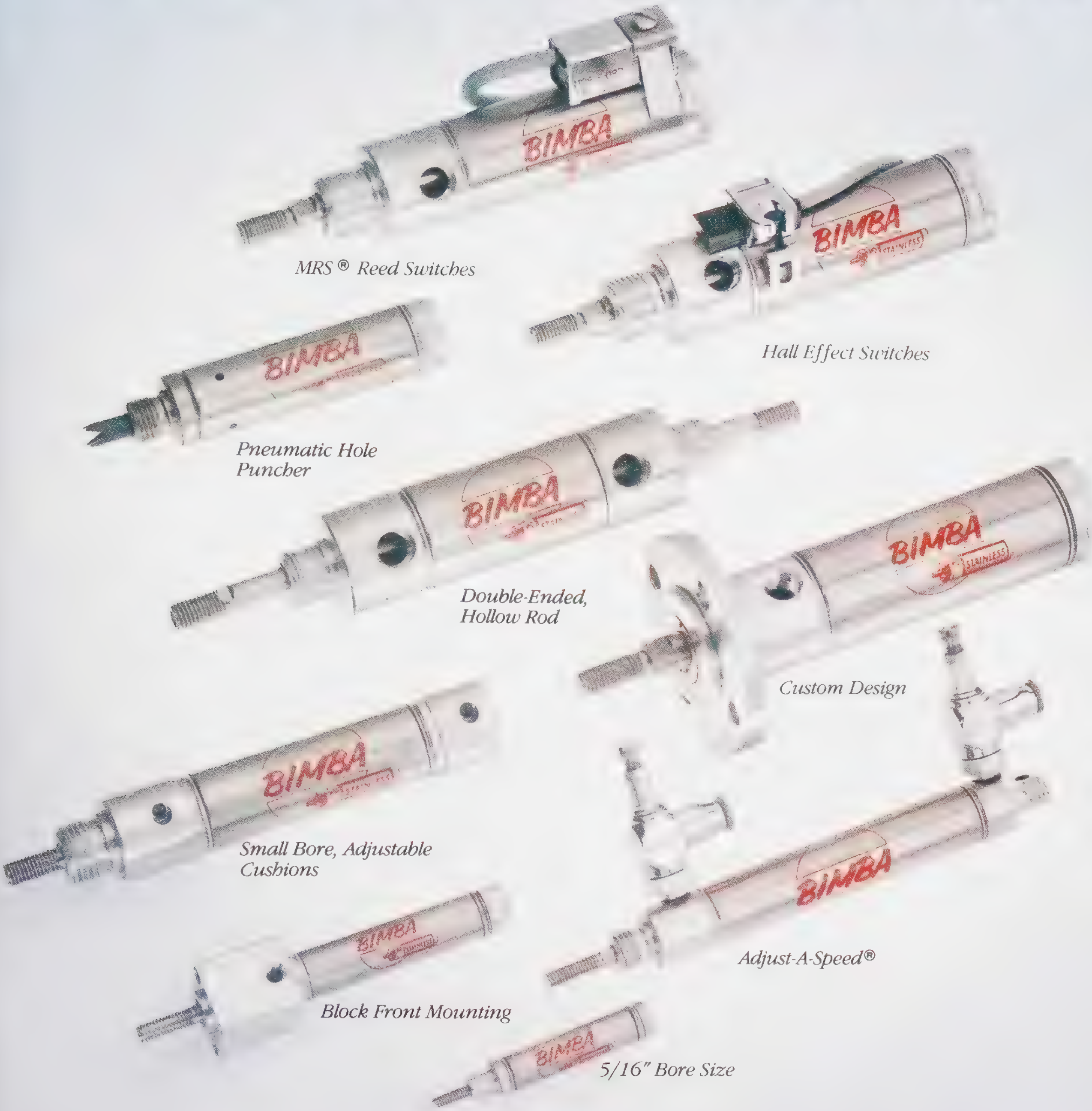
Air over Oil
Converters and Intensifiers
Automatic Leakage Compensation
Pressure Multiplier from 1:1 to 1:20

For catalog
call or write to
[illegible]

SPECKEN DRUMAG
525E Woodlawn Ave., Maple Shade, N.J. [illegible]
[illegible] Fax [illegible]

Circle 536

MORE DESIGN SOLUTIONS



Bimba, originator of unitized, stainless steel ody cylinders, offers you more solutions to your esign problems. Choose from 12 bore sizes, /16″ to 3″, in 8 mounting styles. Over 1500 talog models include solutions to:

☐ Position Sensing with Hall Effect or Reed Switches
☐ Speed Control with Pre-Mounted, In-Port Flow Controls
☐ Load Deceleration with Patented, Adjustable Cushions
☐ Noise Reduction with Built-In Bumpers

BIMBA AIR CYLINDERS... ENGINEERED TO MEET YOUR NEEDS

If one of many catalog models doesn't meet your requirements, we'll design a custom cylinder for your unique application. Thousands of custom models have been developed to solve a variety of design problems.

Specifying is simplified by using our Product Selection Software. Testing your idea is easy with our free OEM Sample Program. Contact your local Bimba distributor for details. Send for your free price/catalog today!

Bimba Manufacturing Company,
P.O. Box 68, Monee, IL 60449.
Telephone (708) 534-8544. Fax (708) 534-5767.

Circle 537

BIMBA STAINLESS ®

TURN TO BIMBA

BIMBA PNEU·TURN ROTARY ACTUATORS... RELIABLE PERFORMANCE AT A LOWER COST

Over 30 years ago, Bimba Manufacturing Company developed and pioneered the world's first unitized, stainless steel body, air cylinder. By applying years of experience in manufacturing lightweight, compact, low cost linear actuators, Bimba has achieved a breakthrough in rotary actuator design. The Bimba Pneu-Turn offers you a rack and pinion type rotary actuator built with quality components that are streamlined for maximum space and weight savings. This design gives you reliable performance at a considerable savings.

The Bimba Pneu-Turn offers these standard features for optimal performance:

☐ Cylinder Bodies - 304 Stainless Steel For Maximum Seal Life.
☐ Shaft - High Strength, 303 Stainless Steel For Long Life.
☐ Piston Seals - Buna "N", U-Cup Type For Low Breakaway Friction.
☐ Rack - Case Hardened, Carbon Steel For Maximum Wear Resistance.
☐ Pinion - High Strength, Alloy Steel For Greater Durability.

For maximum design flexibility in light and medium duty applications that require the ultimate in a space-saving, lightweight rotary actuator, choose the Bimba Pneu-Turn. Select from five bore sizes, 9/16", 3/4", 1-1/16", 1-1/2", and 2", with five standard angles of rotation and a wide range of torque capabilities. Solve your tough design problems with many standard catalog options.

Learn more about how the Bimba Pneu-Turn can offer economical answers to your automation problems. Turn to Bimba for solutions! Contact your local Bimba Distributor or send for your free, price/catalog today!

Bimba Manufacturing Company,
Monee, Illinois 60449-0068,
Telephone: (708) 534-8544
FAX: (708) 534-5767

BIMBA
PNEU·TURN®
ROTARY ACTUATOR

Circle 538

TIGHT SPACE?

THE BIMBA FLAT-1® SERIES OF STAINLESS STEEL BODY AIR CYLINDERS WILL FIT RIGHT IN!

Flat-1®

Flat-1 air cylinders offer a space saving of up to 70% in overall length. This means reduced weight and cost for you. Quality features include stainless steel bodies and piston rods, oil impregnated bushings, and anodized aluminum heads for better performance and long cylinder life. Available in eight bore sizes from 9/16" to 4" with 1/8" to 4" stroke lengths. Select from nine standard mounting options. Custom designs are welcomed to meet your special needs.

Square Flat-1®

Flat-1 quality features in a design minimizing mounting dimensions. Designed for bottom flush or front or rear face, horizontal mounting in tight quarters. Cylinders can be mounted side by side in minimal space. Available in four bore sizes 3/4" to 2" with 1/8" to 4" stroke lengths.

Flat-II®

Flat-II double-acting cylinders are designed for applications where piston rod rotation cannot be tolerated and space is at a minimum. Non-rotation is achieved with dual piston rods and a precision end block that assures the rods work in tandem. Eliminates the need for bulky, cumbersome, external alignment devices to save space and reduce cost. Available in four bore sizes from 3/4" to 2" with 1/8" to 4" stroke lengths.

BIMBA STAINLESS®

Bimba Manufacturing Company
Monee, Illinois 60449-0068
Telephone: (708) 534-8544
FAX: (708) 534-5767

Circle 539

Call or write for your free price/catalog today!

BIMBA TRANSFERS THE POWER.. TO YOU

BIMBA
ULTRAN™
RODLESS CYLINDER

Bimba Ultran™ Rodless Cylinder Give You the Power to:

- Reduce Machine Size and Weight
- Lower Costs
- Improve Machine Efficiency

All rodless cylinders give you the advantage of longer strokes in less space. The Bimba Ultran rodless cylinder gives you more!

- Magnetically-coupled design provides leak-free construction
- Higher magnetic coupling strengths than similar models
- Miles of maintenance-free travel
- Cylinder bodies of 304 stainless steel for long, reliable life

Choose from four bore sizes, $\frac{9}{16}$", ¾", 1$\frac{1}{16}$" and 1½", in stroke lengths of up to 80 inches (up to 40 inches in $\frac{9}{16}$" bore). Many standard catalog options are available, including end-o stroke position sensing. And our Product Selection Softwa for the Ultran rodless cylinde can help you quickly add the cylinder directly to your CA designs.

Find out how the Bimba Ultran rodless cylinder can h solve your design problems. Contact your local Bimba distributor or send/call for y free price/catalog today!

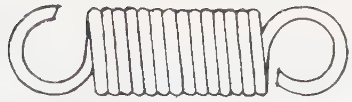
Bimba Manufacturing Comp
P.O. Box 68, Monee, IL 60
Telephone (708)534-8544.
Fax (708)534-5767.

BIMBA
STAINLESS

Circle 540

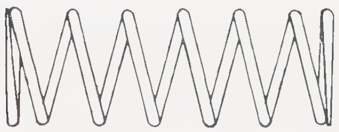
Made in U.S.A.

OVER 30 YEARS OF QUALITY AND INNOVATION



Design springs in seconds on your PC with SPRINGPac . . .

SPRINGPac can be used for the design, testing and validation of **extension, compression, torsion, flat, motor,** or **belleville** springs.



Developed by Engineering Software Co.

- Accommodates both static and fatigue loading using either the British or Metric system
- Spread-sheet type formats simplify problem definition
- Pop-up windows let you immediately access data
- Built-in design library contains 14 different spring materials, or
- Accepts user-defined materials
- Spring design process is completely interactive. Instructions and examples may be viewed anytime during a design session
- Graphics present a profile of the proposed spring design
- Designs can be saved for subsequent retrieval or revision
- Complete technical support with telephone back-up
- Computer disks are not copy protected

SPRINGPac IBM disks and user manual $495

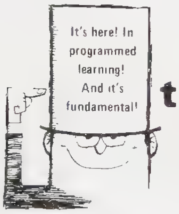
SYSTEM REQUIREMENTS:
IBM PC/XT/AT or compatibles
PC/MS DOS 2.0 or higher
256K minimum memory
CGA or EGA support

SATISFACTION GUARANTEED! Use SPRINGPac on your PC. If the program doesn't perform as described, just return it within 30 days for full refund or credit.

Chargecard users order toll-free 800-321-7003

(in Ohio 216-696-7000)
Penton Education Division
1100 Superior Avenue
Cleveland, Ohio 44114

Circle 541


It's here! In programmed learning! And it's fundamental!

the fundamentals of metal casting

Penton Education Division has recently designed a new programmed learning course to quickly and easily familiarize you with metal casting.

Proceeding in the step-by-step format of programmed learning, which maximizes comprehension, THE FUNDAMENTALS OF METAL CASTING covers the few basic principles needed to understand how a metal behaves as it is cast; the different materials and techniques used in making molds and mold cores for casting; and the properties, performance, and castability of different metals that are commonly cast.

Completing this course at your own pace should require no more than several evenings. When you have finished, you will be able to test your comprehension.

☐ Please send ______ copies of "The Fundamentals of Metal Casting" at **$20.00** each.

☐ Check enclosed ☐ P.O. #______________ enclosed.

☐ Bill my company and include shipping and handling charges.

☐ Please send further information.

Name ______________________

Title ______________________

Company ______________________

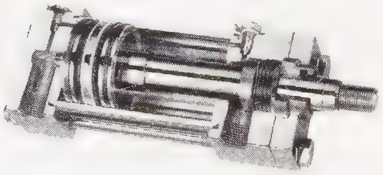
Address ______________________

City, State, Zip ______________________

Penton Education Division
1100 Superior Avenue • Cleveland, Ohio 44114

- ***Rods**
- ***Seals**
- ***Bushings**
- ***Cushions**
- ***End Caps**
- ***Flanges**
- ***Ports**
- ***Mounts**
- ***Retainers**
- ***Wipers**
- ***Springs**
- ***Piston**
- ***Packing**
- ***Trunnion**
- ***Stop Tube**
- ***Connections**
- ***Switches**
- ***Valves**
- ***Manifolds**
- ***Feedback**

MODIFIED STANDARD CYLINDERS* for SPECIAL PROBLEMS



We specialize in combining standard catalog cylinders with modified parts, creating custom cylinders.

We deliver unique cylinder solutions at near standard pricing by changing the part's size, configuration, material used, etc., etc.–and we will make these modifications for any number of cylinders, even one!

So when you know a standard NFPA mounting flange, rod style, seal or whatever, won't do the job, give us a call. We'll make a cylinder that's just right for you.

milwaukee Cylinder
a **versa\tek** company

5877 South Pennsylvania Avenue • Cudahy, WI 53110
Call: 1-800-521-6416 • Fax 414-769-0157

Circle 542

FLUID-POWER SYSTEMS

Write this number on the Reader Service Card to receive information from all advertisers making the listed products.

POWER INPUT AND STORAGE

1308	Assemblies, aircraft
1309	Assemblies, marine
1310	Assemblies, mobile
1311	Assemblies, other
1312	Boosters
1313	Drives, hydraulic pump
1314	Drives, hydrostatic
1315	Gerotors
1316	Intensifiers
1317	Power units
1318	Pumps
1319	Pumps, centrifugal
1320	Pumps, rotary
1321	Pumps, vacuum
1322	Systems, aircraft
1323	Systems, industrial hydraulic
1324	Systems, marine
1325	Systems, mobile
1326	Systems, pneumatic
1327	Systems, vacuum

POWER MODULATION & CONTROL

1328	Breakers
1329	Burners
1330	Computers, hydraulic
1331	Controls
1332	Dispensers
1333	Dividers, flow
1334	Faucets
1335	Fluidics
1336	Instruments & controls
1337	Logic, moving-part
1338	Manifolds
1339	Nozzles
1340	Orifices
1341	Panels, control
1342	Pistons
1343	Poppets
1344	Regulators
1345	Servosystems
1346	Servovalves
1347	Switches, liquid level
1348	Transducers, fluid to mechanical
1349	Transducers, hydraulic
1350	Transducers, pneumatic
1351	Valves, block
1352	Valves, check
1353	Valves, directional-control
1354	Valves, flow-control
1355	Valves, other
1356	Valves, pressure
1357	Valves, pressure-control
1358	Valves, proportional flow
1359	Valves, relief
1360	Valves, solenoid
1361	Venturies

ACTUATORS, MOTORS & SHOCK ABSORBERS

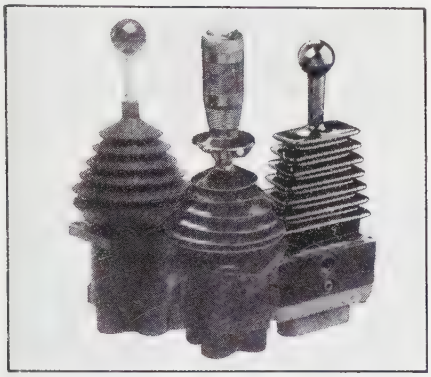
1362	Actuators, rotary
1363	Cylinder mounts
1364	Cylinders
1365	Gas springs
1366	Linear devices
1367	Motors, air
1368	Motors, fluid
1369	Motors, other
1370	Rams

FLUIDS, CONDUCTORS & CONDITIONERS

1371	Accumulators
1372	Adapters
1373	Anemometers
1374	Baffles
1375	Compensators
1376	Counters, pneumatic
1377	Couplings
1378	Ducts
1379	Evaporators
1380	Filters
1381	Fittings
1382	Flanges
1383	Flowmeters
1384	Fluids, heat transfer
1385	Fluids, hydraulic
1386	FRLs
1387	Gages
1388	Heat exchangers
1389	Heaters
1390	Hose
1391	Indicators
1392	Joints
1393	Manometers
1394	Meters
1395	Mufflers
1396	Pipe
1397	Pressure vessels
1398	Radiators
1399	Reservoirs
1400	Rotameters
1401	Screens
1402	Storage, fluid
1403	Strainers
1404	Test equipment
1405	Timers, pneumatic
1406	Tubing
1407	Unions
1408	Vents, breather

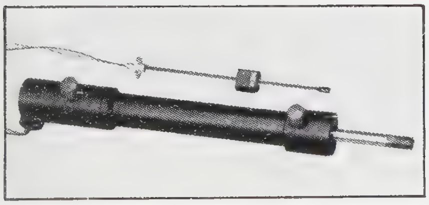
Oil hydraulic remote controllers

Commercial Intertech provides high performance for precision applications. This advanced design results in practically zero hysteresis. Operating pressures from 400 to 650 psi. Flow required 2 to 5 gpm. Commercial Intertech, Hicksville, OH 43526. (419) 542-6611. **Catalog H-113.** Circle 820



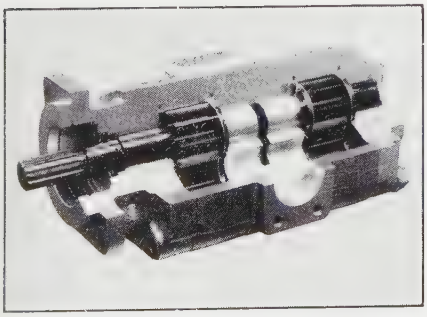
A "smart" cylinder with .002" repeatability

Ideal for situations where space constraints would otherwise limit design flexibility. Pressures to 5000 psi. 500 million inches travel life. Stroke lengths from 1¾" to 4". Several types of programmable controls. Commercial Intertech, Oildyne Division, Minneapolis, MN 55428. (612) 533-1600. **Bulletin OD-115.** Circle 821



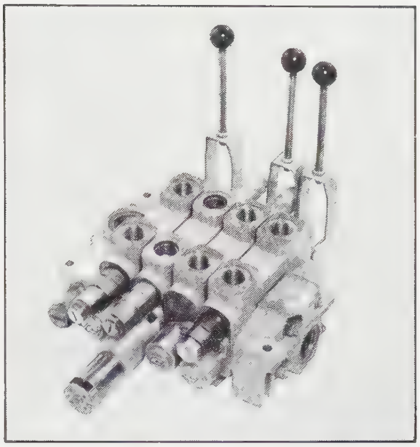
3500 psi gear pumps and motors

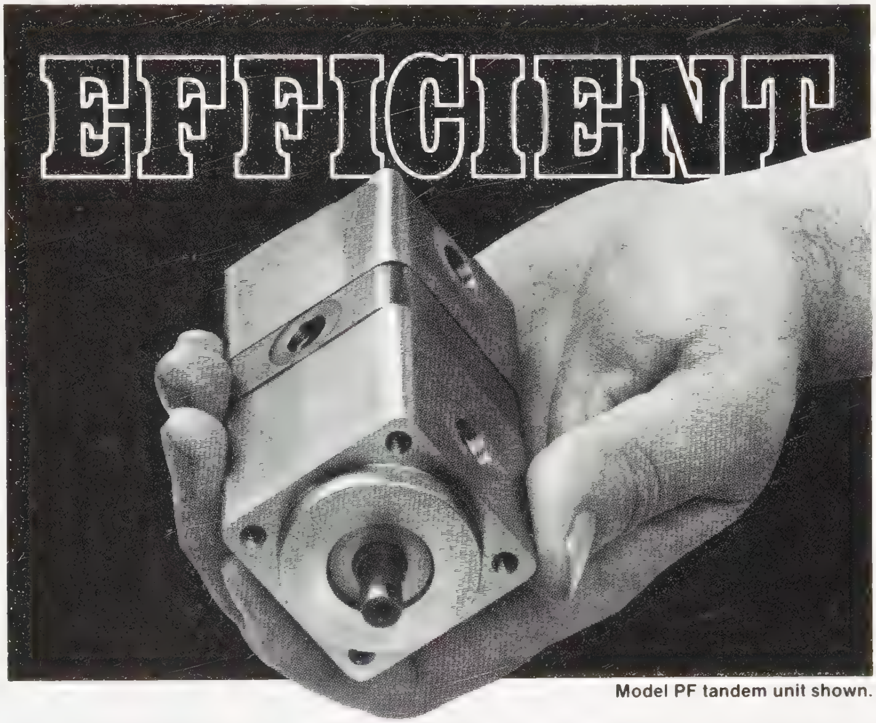
P315™/P330™/P350™/P365™ pumps and motors operate at up to 95 percent efficiency on hydraulic oil and fire-resistant fluids. Outstanding starting and running torque. Motor speeds to 2400 rpm. Single and multiple units. Commercial Intertech, Youngstown, OH 44501-0239. (216) 746-8011. **Catalog H-73.** Circle 822



Directional control valves

Commercial's VA™ and VG™ model valves provide full-flow port relief, lower lever effort and easy service features. They offer a wide variety of controls in a full range of work sections in series and parallel circuits for more efficient operation of earthmoving, refuse and material-handling and other heavy-duty mobile equipment. VG 20 and 35 control valve models are rated at 3500 psi, 40 gpm and 70 gpm. VA 20 and 35 models at 2500 psi, 40 and 70 gpm. Commercial Intertech, Hicksville, OH 43526. (419) 542-6611. **Catalog H-99.** Circle 823





Model PF tandem unit shown.

Commercial's mini piston pumps and motors operate on extremely thin fluids to 3500 psi

These outstandingly efficient mini pumps and motors are available in single and tandem configurations. Plus they offer:

- 1/10 to 2 cc displacement per rev per pump.
- Very quiet operation.
- AC or DC electric motor pump drives available from 1/10 to ½ hp.
- High volumetric efficiency. Tests run on 1 cS viscosity fluid at 300° F showed efficiency over 60% at 1500 psi.
- A single pump will fit into a 2" cube.
- -40° F to +300° F operating range.
- Fixed displacement.
- Naturally aspirated pumps can fill to 5000 rpm.

Call for a quote

Commercial's mini piston pumps and motors are available as standard units. Or we'll quote and build to your specifications.

Catalog KH-103 Circle 824

OILDYNE
A UNIT OF COMMERCIAL INTERTECH

4301 Quebec Ave. N. Minneapolis, MN 55428 (612) 533-1600 Fax: (612) 533-0082

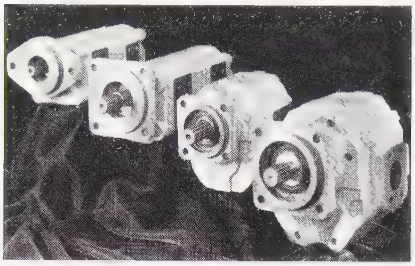
...putting technology to work worldwide

180-334 WE

© Commercial Intertech Corp

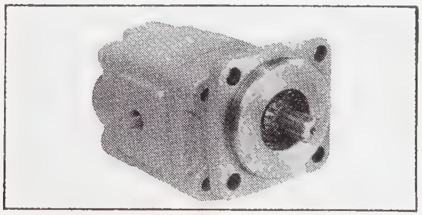
Gear pumps and motors

P31™/P51™/P76™/P125™ pumps and motors for heavy-duty mobile equipment provide high performance and excellent reliability in pump sizes from 1.97 to 6.47 cid per inch of gear width and motor sizes to 175 hp. All models are available as single or multiple assemblies. Porting can be through the sides or through the port end cover. New motor gear design offers high starting torque and smoother torque ripple. Commercial Intertech, Youngstown, OH 44501-0239. **Catalog H-58.** Circle 825



Small gear pumps for small trucks and tractors

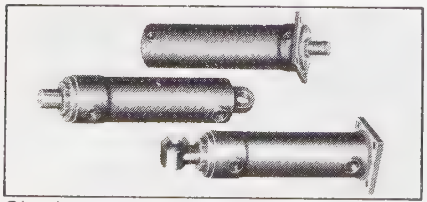
Commercial's new P20 gear pumps and motors offer big performance in a small package for hoist and wrecker body trucks. A P20 with ½″ gears measures just under 6″ from mounting flange to port end and weighs less than 25 lbs.



The cast iron P20 produces flows up to 2.96 cir at 3000 psi; output of up to 3.94 cir is available at 2500 psi. Maximum speed is 2400 rpm. Commercial Intertech, Youngstown, OH 44501-0239. Circle 826

Single- and double-acting cylinders

A wide variety of lengths and mountings are available for mobile applications in diameters of 1½″ to over 9″.

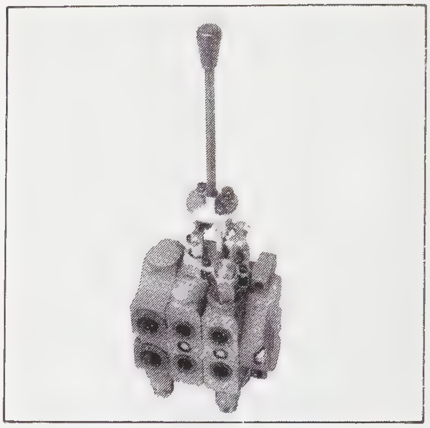


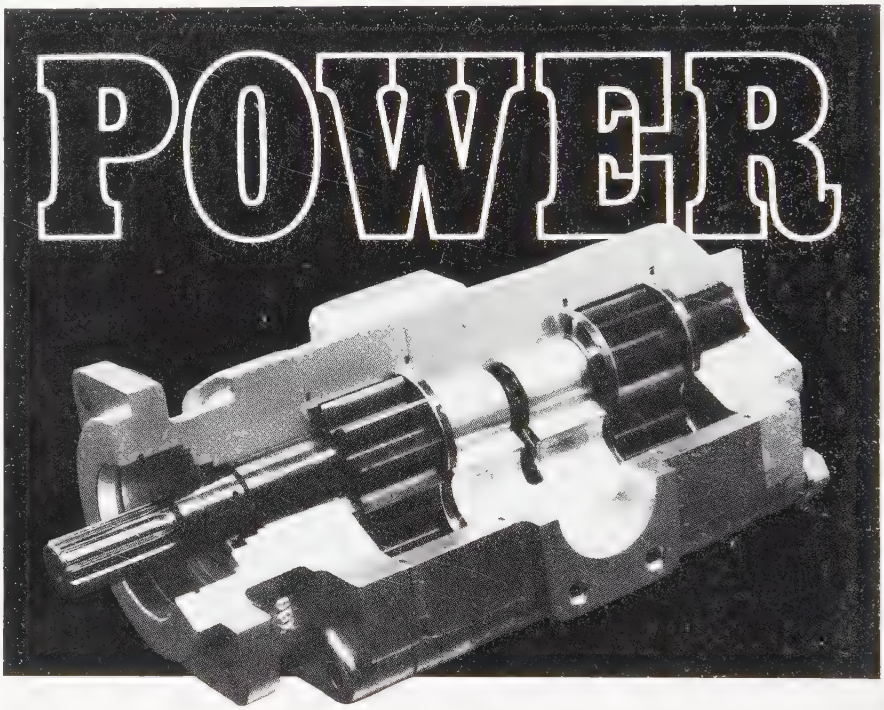
Single-stage and telescoping cylinders, both single-acting and double-acting, meet your need for reliability in the field and easy service in the shop. Commercial Intertech, Youngstown, OH 44501-0239. **Catalog H-52** (single-acting cylinder). **Catalog H-53** (double-acting cylinder). Circle 827

Kontak hydraulic valves now from Commercial

Kontak valves are now available exclusively from Commercial Intertech and are manufactured in the company's own facilities. These KA 18 valves feature exceptional reliability and versatility at pressures to 3500 psi with nominal flow to 22 gpm. Commercial Intertech, Hicksville, OH 43526, (419) 542-6611. **Catalog H-117.**

Circle 828





300-series pumps and motors offer reliable, cost-effective performance at pressures to 3500 psi

Commercial's cast iron pumps produce flows from 6 to over 200 gpm (with multiple pump sections) at volumetric efficiencies as high as 95 percent. Our gear motors have outstanding starting and running torque. Both offer the economy and durability characteristic of gear equipment. Pumps are available in sizes from 1.24 to 3.6 cid per inch of gear width. Gear motors available in sizes to 175 hp. SAE A, B or C two-bolt mountings and drive shafts are included.

The 300-series pumps and motors are in widespread operation in marine hydraulics and off-highway equipment, trucks, refuse vehicles and wreckers as well as on generator sets and other stationary applications. Ask for **Catalog H-73**.

® **Commercial Intertech**

Box 239 Youngstown, OH 44501-0239 Phone: (216) 746-8011

...putting technology to work worldwide

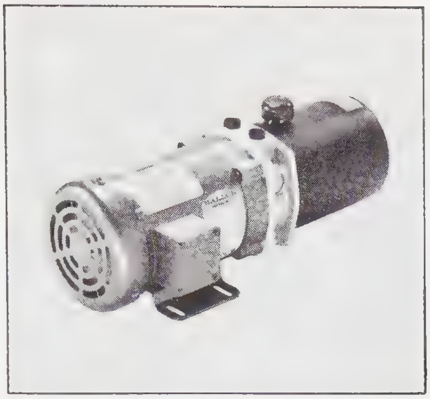
Commercial Intertech 180-364 PM

Circle 829

Heavy-Duty Hydraulic Power Units

Oildyne's Series 500 power units provide up to 3 gpm at pressures to 3000 psi for heavy-duty industrial fluid power applications. These completely self-contained power units include AC motor, hydraulic gear pump, reservoir, internal valving, pilot-operated load-holding checks and relief valves. They're available in single directional or bidirectional units. Oildyne, 4301 Quebec Avenue North, Minneapolis, MN 55428. **Catalog OD-110.**

Circle 830



Put the power where you need it with Oildyne Series 108 Hydraulic Power Units

Oildyne compact power units are completely self-contained with an AC or DC motor, gear pump, oil reservoir, internal valving, and pressure and thermal relief valves. Less than 6½" wide, 9½" tall, Oildyne power units offer:

- flows to ¾ gpm — three basic pump sizes
- pressures to 3500 psi
- 12 or 24 VDC or AC motors
- locking check valves and relief valves standard

Proven in marine motor tilt and trim units, drives, leveling jacks, medical chairs and apparatus, and many other applications.

Single direction units are commonly used to charge accumulators, power one-way hydraulic motors, provide pilot flow to servo valves, pressurize lube systems and supply multi-function circuits with external valving. Bidirectional or reversible units operate double-acting cylinders and two-way motors.

Oildyne power units can be easily modified for increased displacement where lower pressure is required and can be tailored for intermittent or continuous service. Call or write our specialist in compact fluid power.

Catalog OD-108

Circle 834

OILDYNE A unit of Commercial Intertech Corp

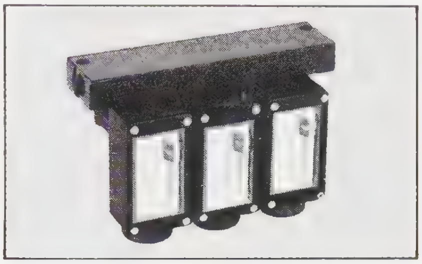
4301 Quebec Avenue North Minneapolis, MN 55428 (612) 533-1600

...putting technology to work worldwide

180-202-3 OD

Oildyne Pressure Switches

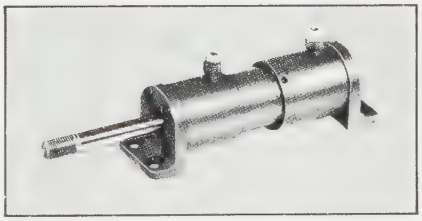
Oildyne compact single and duplex pressure switches are totally enclosed and designed for rugged duty. The moving parts are designed so that the switch may be used in any mounting orientation. Heavy-duty electrical contacts are rated for 15 amps at 125, 250 or 460 VAC, and 10 amps at 12, 24 or 36 VDC. Open and normally closed contacts are supplied. A simple change in springs allows the switch to be used through a wide range of pressure settings. Special triplex models and subplates for in-line mounting are available. Oildyne, 4301 Quebec Avenue North, Minneapolis, MN 55428. **Cat. 728-1.**



Circle 831

Double-Acting Cylinders

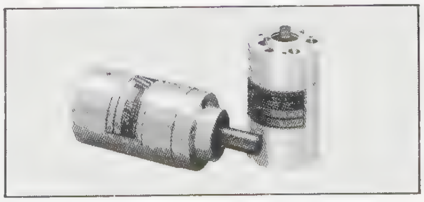
Oildyne double-acting hydraulic cylinders are offered in sizes from ½" to 3" bores and pressure ratings to 5000 psi. Minimum stroke length is 2¾" and weights start at 7 oz. To meet varied job requirements, a wide choice of mountings and accessory equipment, including male and female portings for double rod end cylinders are available. Oildyne, 4301 Quebec Avenue North, Minneapolis, MN 55428. **Cat. OD-109.**



Circle 832

High-Speed Miniature Motors

Less than 2" in diameter and 3" long, Oildyne's 09 Model hydraulic gear motors operate at speeds to 25,000 rpm (2560 rev./gal.) and pressures to 5000 psi. Maximum torque is 65 in.-lbs. They're instantly reversible and can be stalled indefinitely without damage. Starting torque is 12 in.-lbs. per 1000 psi. Oildyne, 4301 Quebec Avenue North, Minneapolis, MN 55428. **Cat. OD-109.**

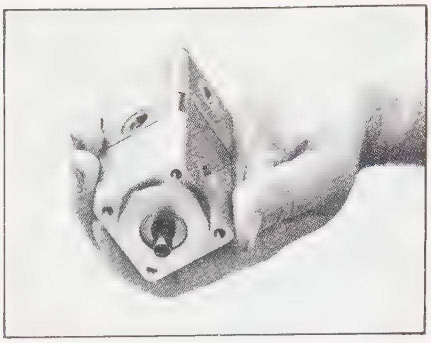


Circle 833

Mini piston pumps and motors

These outstandingly efficient, mini piston pumps and motors will operate on extremely thin (1 cS) fluids to 3500 psi. Available in single and tandem models with displacements from 1/10 to 2 cc.

Features include very quiet operation, 1.10 to ½ hp, fixed displacement, -40°F to +300°F operating range. A single pump will fit into a 2″ cube. Naturally aspirated pumps can fill to 5000 rpm. AC or DC electric motor drives also available.



Commercial Intertech, Oildyne Division, Minneapolis, MN 55428. (612) 533-1600. **Catalog KH-103.**

Circle 835

Proven with electric, pneumatic, hydraulic and manual controls, Commercial's VA™ and VG™ model valves provide full-flow port relief, lower lever effort and easy service features. They offer a wide variety of controls in a full range of work sections in series and parallel circuits for more efficient operation of earthmoving, refuse and material-handling and other heavy-duty mobile equipment. VG 20 and 35 control valve models are rated at 3500 psi, 40 gpm and 70 gpm. VA 20 and 35 models at 2500 psi, 40 and 70 gpm. **Catalog H-99.**

Circle 836

® Commercial Intertech

373 Meuse Argonne Hicksville, OH 43526 Phone: (419) 542-6611

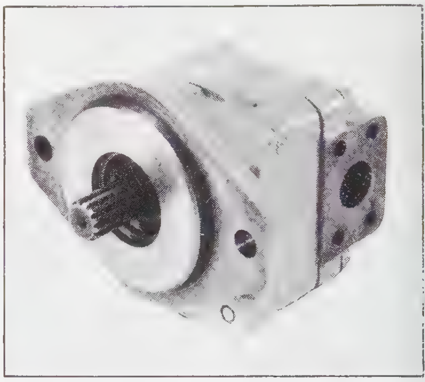
...putting technology to work worldwide

© CIC 180-335-1 VD

© Commercial Intertech Corp

P315™ gear pumps for high-pressure performance

These 3500 psi units offer 1.24 cubic inches per inch of gear width. Other features of the P315 series include SAE A and B two-bolt mountings and drive shafts. Commercial Intertech, Youngstown, OH 44501-0239. (216) 746-8011. **Catalog H-106.** Circle 837



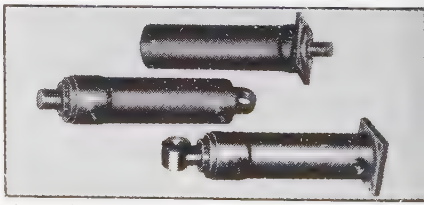
Small 2500 psi pumps

Commercial's G101 pump/valve assembly is a compact hydraulic power source for smaller dump trucks and hoist bodies. The G101 is based on Commercial's long-proven P30 gear pump design. It reliably produces 21 gpm or 29 gpm in 1.5″ or 2″ gear sizes, respectively, at 1800 rpm. Maximum working pressure is 2500 psi, maximum speed 2500 rpm.

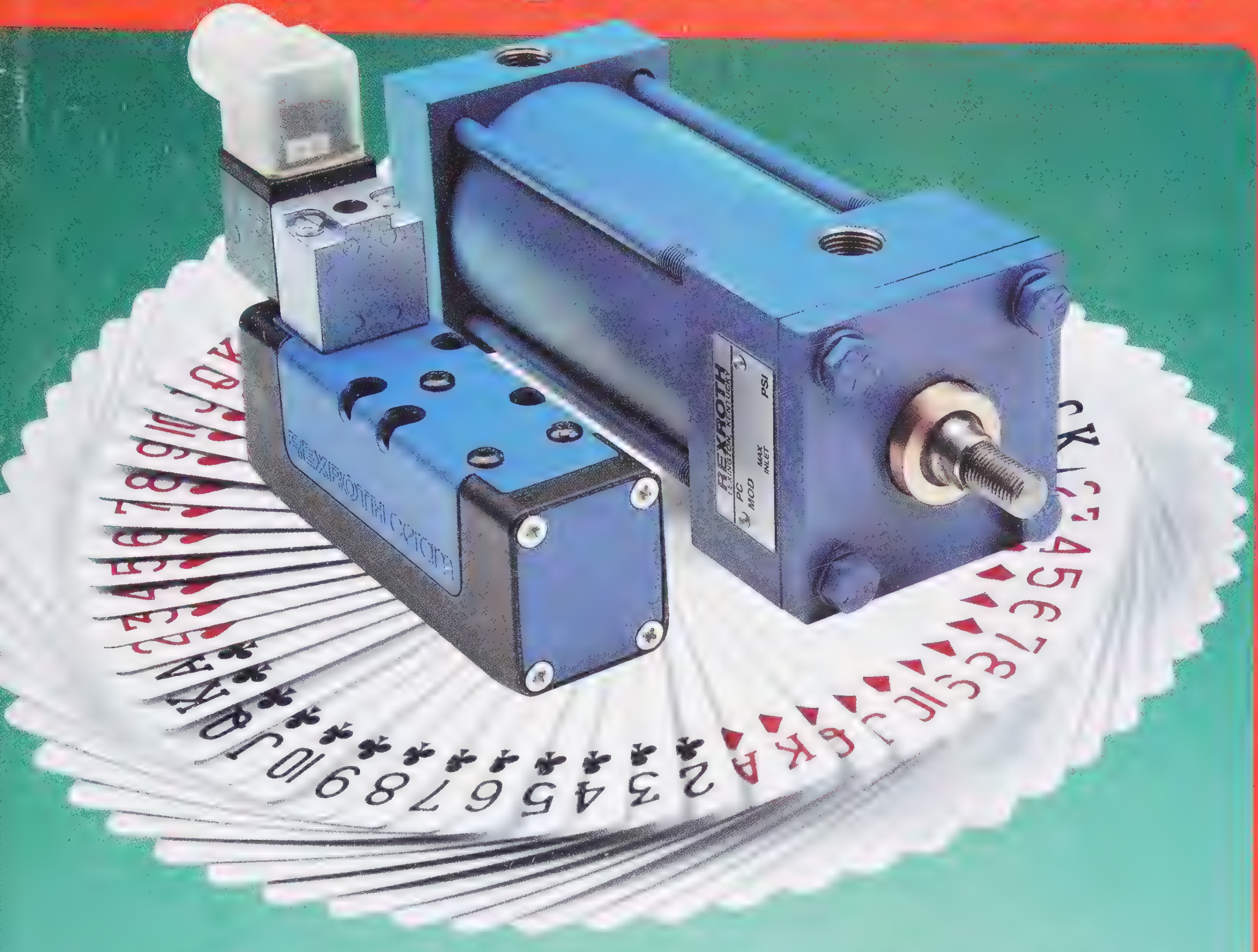
Pump output is controlled by a two-way, three-position valve built into the port end cover. The valve may be actuated by remote cable or pneumatic controls in the truck cab. Commercial Intertech, Youngstown, OH 44501-0239. (216) 746-8011. **Catalog H-71.** Circle 838

Single- and double-acting cylinders

A wide variety of lengths and mountings are available for mobile applications in diameters of 2½″ to over 9″. Single-stage and telescoping cylinders, both single-acting and double-acting, meet your need for reliability in the field and easy service in the shop. Commercial Intertech, Youngstown, OH 44501-0239. (216) 746-8011. **Catalog H-52** (single-acting). **Catalog H-53** (double-acting). Circle 839



We're playing with a *full* deck...



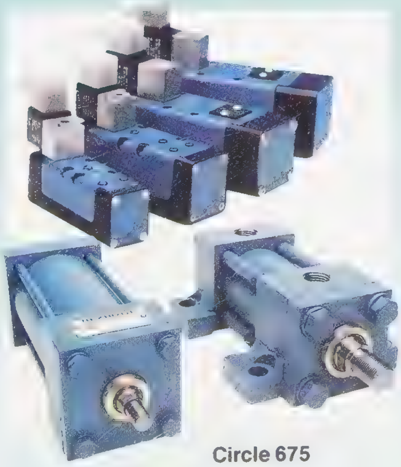
...when it comes to *valves* and *cylinders*

Rexroth Pneumatics Division offers a full complement of valves and cylinders to satisfy virtually any requirement for industrial equipment control systems.

Rexroth Pneumatics supplies more than a quarter-million valves and cylinders every year to push, pull, move and control the wheels of industry...from the new generation Ceram™ Pneumatic Directional Control Valves to NFPA Pneumatic and Hydraulic Cylinders.

The Ceram Valve incorporates **sliding ceramic plates**—the very latest pneumatic valve sealing technology—which eliminate spools and sliding seals, and shrug off contaminants. Available in ISO sizes 1 through 4, this rugged valve provides long life in even the harshest environments.

Our NFPA Cylinders are offered in 19 standard mountings, bore sizes from 1½″ through 14″, and a wide variety of rod sizes and custom modifications.



These products typify our broad line of valves and cylinders developed to meet today's changing control and actuating requirements. Next time you have a requirement, consider Rexroth Pneumatics and draw from a full deck. For more information, call or write:

THE REXROTH CORPORATION
Pneumatics Division
1953 Mercer Road, Lexington, KY 40511
Tel 606-254-8031 • FAX 606-233-0958

a **mannesmann** technology company

REXROTH
WORLDWIDE PNEUMATICS

Mastering the Technology

Circle 675

CAD/CAM

Software for analysis and design

CAD peripheral hardware

Computer hardware

A
Autorouting 790
B
Benchmarks 766
Boards, graphics 822
C
CGA 767
CSG 782
Cisc 768
Color printing 814
D
Data entry 808
Database management 800
Digitizers 808
Drafting and design 775
E
EGA 767
Electrostatic plotters 820
F
Finite-element analysis 784
Frame buffer 769
G
Geometric modeling 781
H
Hardcopy output 810
Hercules graphics 767
Hierarchical DBMS 800
K
Kinematics 796
L
Laser printing 810
Local-area networks 773
M
Mainframes 770
Mass storage 824
Mechanical CAE 775
Mice 808
N
Near-supercomputers 769
Networking 773
P
PGA 767
Parametrics 776
Personal computers 765
Photocapsule process 818
Plotters 814
Pre and postprocessors 786
Printers 810
R
Raster scan 818
Risc 768
S
Scalar processing 770
Scanning 812
Solid modeling 781
Supercomputers 769
Surfaces 782
T
Terminals 818
Thermal analysis 798
Time sharing 772
Trackballs 808
Turnkey systems 771
V
VGA 767
Vector processing 770
Virtual memory 771
W
Wire-frame modeling 781
Workstations 768
X
XGA 767

Advertisers

Algor, Inc. .... IBC
American Small Business Computers, Inc. 783,787,797,805
Aries Technology, Inc. 789
Cadkey, Incorporated 791-794
Calcomp, A Lockheed Company 808
Computervision 777-780
Evolution Computing 802-803
Houston Instrument .. 810-811,813-821,823
Intergraph 799
Micro Engineering Solutions 801
Northern Research & Engineering Corporation 806
Pacific Data Products 827
Plan Hold Corporation 830
Structural Research and Analysis Corporation 785
Swanson Analysis Systems, Inc. 774

Computer hardware

The trend in hardware is still toward more horsepower at lower cost. The result: Increasingly blurred distinctions between equipment categories.

The typical computer running CAD/CAM applications today sits on a desktop. It may be networked to other similar machines and to larger machines. Applications running on networks may employ a variety of central facilities such as file servers or gateways to access resources held outside the user's local computing station.

The typical desktop computer consists of a motherboard, switching power supply, detachable keyboard, mass storage peripherals, and a CRT monitor. The motherboard holds the guts of the computer; the CPU and math coprocessor, cache memory, main memory, display driving electronics, and other circuitry needed to interface with external devices such as disk drives, keyboards, and so forth. Motherboard designs also generally can accept plug-in boards containing additional circuity such as more main memory, network cards, or specialized graphics coprocessors.

In contrast to machines based on motherboards, some desktop computers instead employ a passive backplane design. Here all circuitry resides on circuit boards that plug into the backplane. The backplane provides connections between boards.

Low-end machines

The most widely used computers in CAD/CAM today are personal computers — general-purpose machines sold retail, through the mail, and through value-added resellers (VARs). Personal computers sold through VARs are often packaged with special peripherals and software to form turnkey systems optimized for specific applications.

It may be useful to review the kinds of personal computer platforms found in CAD applications today. There are two widely used platforms found in the U.S., those based on the 80X86 series CPU, and those based on 680X0 series CPUs.

The IBM PC and PC-compatible machines employ 80X86 CPUs. The first IBM PC and the XT used the 8088 CPU, a processor that computed in eight and 16-bit words. Machines based on the 8088 are still in use today, but generally not in CAD applications that require heavy-duty computations. By modern standards, these machines are slow, generally using a 4.8-MHz clock, and are not optimized for handling the increasingly graphic user interfaces that typify mainstream computing today.

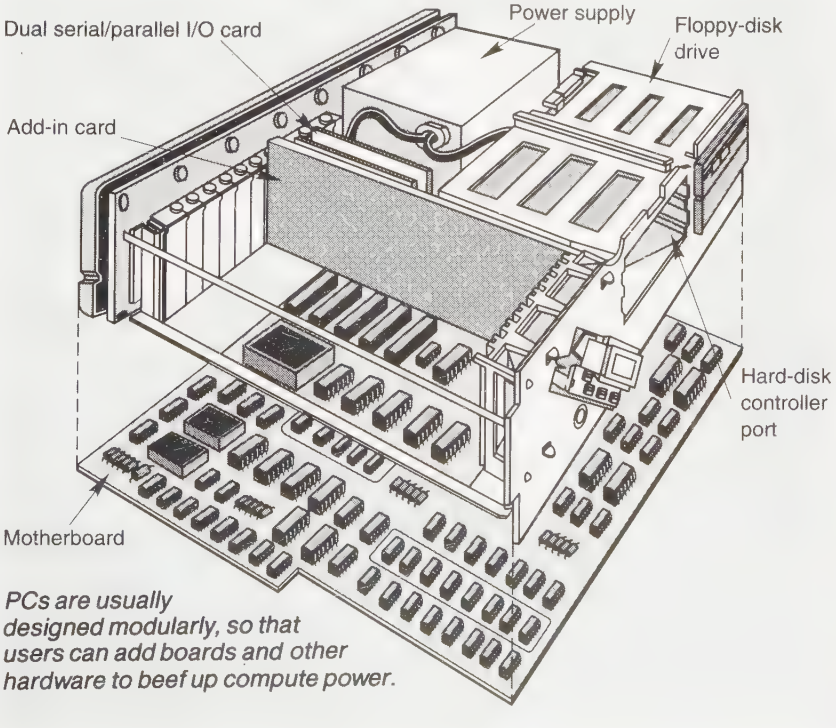
Some early PC-compatible machines used 8086 CPUs rather than the 8088. The 8086 is a purely 16-bit CPU that runs the same 16-bit instructions as used by the 8088. It tended to be slightly faster than 8088-powered machines but, like the 8088, is no longer used in new machines.

In the early days of personal computing, there were a few CAD applications that were designed to run on these venerable machines. In particular, I-beam and member deflection calculations were among the first commercial packages. Simple 2D drafting packages also were available for these machines, most notably the first releases of AutoCad. Spreadsheets, however, were probably the most popular vehicle for CAD work.

The primary drawbacks of these early machines for CAD work were probably their inability to directly address more than 1M byte of main memory, the relative coarseness of their CGA or Hercules graphics, and their speed, or lack of it. The PC AT platform began to address some of these problems. It sported a more powerful 80286 CPU able to directly address 16M bytes of main memory, and better graphics (EGA). It featured a faster clock speed as well. In the heyday of the 80286, 10-MHz AT-compatible machines were widely available, and even faster versions debuted in the later part of the 80286's product lifecycle.

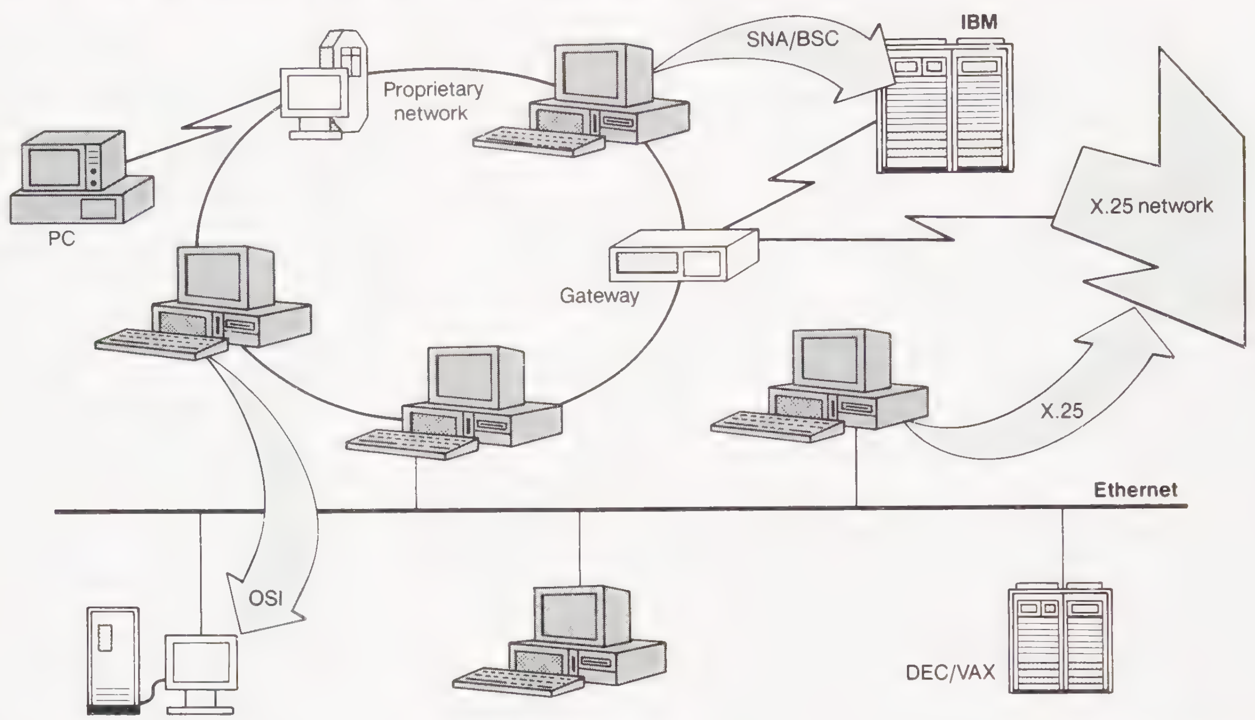
AT-class machines also carried better peripherals. For one thing, they could handle larger hard disks with faster access times. The debut of the AT also marked the first use of 1.44M-byte 5.25-in. floppy drives, an improvement from the 360k DSDD drives of the early PCs and XTs.

These better peripherals and faster compute speeds made AT-class machines popular platforms for CAD ap-



PCs are usually designed modularly, so that users can add boards and other hardware to beef up compute power.

NETWORKING CONFIGURATIONS



Engineering workstations are designed to connect to a variety of networks and other computers. Workstation clusters on proprietary networks can connect through hardware called gateways, while software is used to provide links to standard networks and other hardware. OSI, SNA, X.25, and Ethernet are protocols governing the transfer of information across certain types of networks. Ethernet and X.25 also define standard physical connections in a network. Ethernet is a collision-detection scheme for local-area networking, while X.25 governs wide-area networking. SNA is a proprietary data-networking protocol, while OSI protocols are international standards.

PERFORMANCE MEASUREMENTS

Computer performance measurements can be overwhelming. Among the most confusing measurements are Mips (millions of instructions/sec), and vendors will make Mip rating claims based on several benchmarks. One commonly used rating is the Dhrystone benchmark of integer performance. Another way to derive a Mip rating is to base performance on VAX Mips. However, there is no standard way of deriving a VAX Mips rating. When vendors talk about VAX Mips, they compare the performance of their machines to the integer performance of a VAX/780 minicomputer. Floating-point performance is usually reported in some number of floating-point operations per second (flops) based on the Linpack or Whetstone benchmarks. The Khornerstone benchmark is a set of 22 tests often used to check I/O, CPU speed, and floating-point performance of PCs and workstations.

It is sometimes difficult to interpret benchmark results because of the way tests are designed. For instance, the Linpack suite may not adequately check performance of parallel processing computer because it performs individual vector calculations on array elements. Newer tests can calculate ratings on blocks of data rather than individual vectors. So, they may be more suited to testing performance of computers that use more than one CPU because they limit data transfer between processors.

Also, performance of similar machines may differ depending on how a benchmark is implemented. When running Linpack for one of Argonne National Laboratory's reports on computer performance, for example, vendors can write the linear algebra subprograms that do floating-point calculations in either assembly code or a high-level language like Fortran. Since assembly language runs faster, vendors that run the benchmark using assembly routines may have some performance advantage.

Keep in mind that no truth-in-reporting laws apply to vendors, and they can be counted on to present their products in the best possible light. Some have been accused of doctoring their numbers, and even those who do not cannot consider all the possible factors, such as I/O speed in disk-intensive applications, that could limit performance.

Therefore, raw performance numbers are not the only criteria to use when selecting a computer. It is important to consider the applications that will be done by the machine and the surrounding computing environment.

SORTING OUT PC AND WORKSTATION GRAPHICS

Modeling and simulation has become increasingly important in engineering disciplines. Consequently, the ability to display sophisticated graphics has become important as well. Graphic standards for PCs and workstations have evolved over the years. It may be useful to review the various graphic modes that are now found on various types of machines.

The most recently developed graphic standard is called XGA (for eXtended Graphic Standard). Originally developed by IBM, XGA allows for hardware graphics acceleration and supports up to 1,024 × 768-pixel resolution and 256 colors in an interlaced manner. Today, XGA is implemented in different ways by different manufacturers. An organization called VESA (Video Electronics Standards Association) is working on a standardized way of handling the XGA interface across all standard PC buses.

An earlier IBM graphic standard called the 8514/A provides the same basic resolution as XGA, but with fewer colors. However, equipping 8514/A display adapters with 8514 memory expansion kits allows them to provide 1,024 × 1,024-pixel resolution and 256 colors. It should be noted, though, that 8514/A display adapters have never been used as widely as VGA display adapters introduced at roughly the same time.

IBM's Video Graphics Array (VGA) may be the most widely available PC-compatible graphics standard today. Depending on the operating mode, VGA supports both analog (RGB) and digital monitors. With analog monitors, VGA allows the display of 256 colors out of a palette of 262,144. When displaying 256 colors, VGA provides a 320 × 200-pixel resolution. It can also optionally provide 640 × 480-pixel resolution with two colors and 640 × 480-pixel resolution using 16 colors. These display modes, considered high-resolution modes, work with digital monitors. There are several other modes as well.

There are several different kinds of VGA standards, including Super VGA and MCGA (Multi-Color Graphics Array). MCGA is a subset of the basic VGA. Super VGA generally refers to display adapters with resolution in the 1,024 × 768 range. This is the resolution often found in high-end PCs today. Moreover, there are performance issues associated with 8 and 16-bit implementations of the VGA standard. These differences are quite involved and go beyond the scope of this text.

Graphic standards that include XGA and VGA, originally developed by IBM, are all backward-compatible with older graphic standards in the same series. These older standards include EGA (Enhanced Graphic Adapter) and CGA (Color Graphics Adapter). CGA has a maximum resolution of 640 × 200. At this resolution, CGA displays produce four simultaneous colors; at a 320 × 200 resolution, up to 16 colors simultaneously. EGA produces 640 × 350 resolution with 16 colors. Text and data characters occupy an 8 × 14-pixel matrix, making them more readable than in CGA with its 8 × 8-pixel character matrix.

Another older graphics standard, called the Hercules graphics standard, produces displays with resolution comparable to that of CGA displays. Finally, users may occasionally run into PGC (Professional Graphics Controller) graphics on older PCs. PGC was aimed at the CAD market and provided 640 × 480-pixel resolution and 256 colors simultaneously. PGC was never widely used, mainly because of high prices. The 8514/A effectively replaced PGC, providing better performance at a lower price.

Macintosh II machines from Apple Computer have a basic display resolution of 640 × 480 pixels. The Mac II operating system automatically handles displays of higher resolution. This means that software written for the machine can work with high-resolution monitors without the need for special display-driver software.

The graphics situation changes in workstation-class machines. Typical graphic resolution here is on the order of 1,280 × 1,024. When combined with large 19-in. or bigger monitors, this capability allows users to see large portions of their work, but with sufficient detail for close work.

plications. One gripe about the platform, however, is that the 80286 has a hard time handling GUI (graphic user interface) operating environments, for reasons that are beyond the scope of this text.

Platforms based on the 80386 and 386SX, 486 and 486SX CPUs overcome such problems with the ability to directly address 4G bytes of memory.

The introduction of the 80386 CPU in desktop platforms was significant for a number of reasons. For one thing, it coincided with the first wide use of 3.5-in. floppy diskette drives in PC-compatible machines. For another, it coincided with the debut of the MCA (Microchannel architecture) bus used on IBM PS/2-style desktop machines.

The main thing to note about MCA machines is that their internal structure differs dramatically from that of machines based on the AT-style architecture, also known as the ISA bus. This means that plug-in boards designed for AT-style machines won't work in PS/2s, and vice versa. There is another architecture called the EISA bus which is an extension of the AT bus. The thing to note is that AT-style plug-in boards will theoretically work in EISA machines. There are pluses and minuses associated with all these platform architectures. But discussions of these factors go well beyond the explanations we offer here.

While the 80X86 series of CPUs were evolving, the 680X0 CPUs went through a similar series of improvements. Perhaps the most well-known personal computer based around the 68000 is the original Apple Macintosh. (It should be noted that earlier Apple computers, specifically the Apple II and IIGS, used 6502 and 65816 CPUs. However, these are increasingly rare in CAD environments and are not treated here.)

The 68000 has the ability to directly address 16M bytes of main memory. On the original Mac platform, it was combined with a 3.5-in. diskette drive and up to 512k of main memory (with an upper limit of 4M bytes) in a package that featured a small built-in monitor and a detached keyboard. Hard-disk drives only became available for the first Mac some time after the machine's introduction.

The small screen and other factors made the original Mac of limited interest for CAD applications. Nevertheless, packages that included drafting and printed-circuit board layout applications could be found relatively soon after the introduction of this machine. And updated versions of the original Mac include the 68020-based Mac LC, and the Mac Classic II, which sports a 68030 CPU running at 15.667 MHz with main memory expandable to 10M bytes.

The most common 680X0-based desktop personal computers for CAD applications in the U.S. are most likely

Mac II-series machines. These include the 68020 Mac II, the 68030-based 25-MHz Mac IIci and the 40-MHz Mac IIfx. More powerful 68040 CPUs have been recently introduced in the Quadra 700 and 900 desktop machines, both running at 25 MHz.

Mac II-style and Quadra machines feature a variety of noteworthy strong points too numerous to mention here. However, a point to note is that Mac II and Quadra machines employ a NuBus architecture that accepts plug-in boards built to the NuBus format. This enables these machines to be enhanced with additional capabilities via add-in boards.

PCs versus workstations

The distinctions between personal computers and workstations get fuzzy when it comes to high-end PCs and low-end workstations. Product features start to overlap in these two classes of machines. And price-wise, the two often play in the same ballpark.

As an example, consider the features of two recently released machines. One high-end PC includes a 25-MHz full 32-bit processor with address and data caching, a maximum 64M bytes of main memory, on-board serial and SCSI ports and Ethernet connections, 24-bit video, and a base configuration of a 160M-byte hard drive and 4M bytes of main memory. In comparison, one low-end workstation includes a 33-MHz full 32-bit processor, an upper maximum of 64M bytes of main memory, a base configuration with a similar amount of hard disk space, and can run PC programs that include 1-2-3 spreadsheets and industry-standard database programs.

Distinctions are easier to spot in high-end workstations. From the standpoint of CAD, the single factor that most often separates high-end from low-end workstations is graphics. High-end machines frequently include hardware facilities for speedily generating and manipulating sophisticated 3D graphics. Of course, high-end machines tend to be amply equipped with main memory, data and instruction cache, and video memory to support such graphically intense applications.

Typically, standard microprocessors or complex instruction set computer (Cisc) chips power low-end workstations. Recently, many vendors have introduced faster workstations based on reduced instruction set computer (Risc) chips. Some vendors have even implemented multiprocessor architectures.

One large use of workstations is as front ends to larger host computers. Problems can be set up with the workstations, and uploaded to the host for processing. Workstations typically are used for graphics display and manipulation since this an effective method of off-loading the host. So workstations often include sophisticated graphics display subsystems. The features of a display system are directly related to the processing power present in the workstation and not to the characteristics of the screen itself. Functions such as color fills, line and arc generation, and rotation are controlled by the display processor and associated

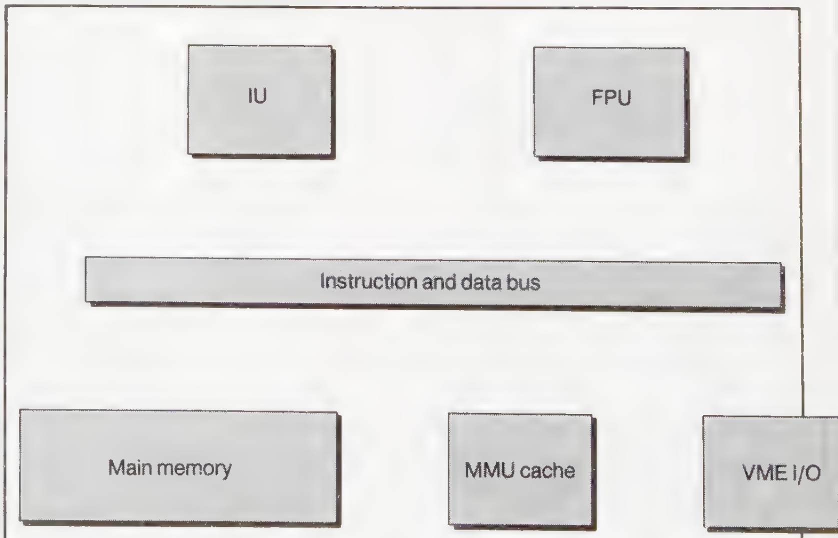
RISC AND CISC

Modern workstations increasingly employ Reduced instruction-set computing (Risc) as a means of obtaining higher performance. The first Risc computer was developed in the late 1970s by researchers at IBM, who discovered that 80% of a typical computer application uses only 20% of the available instructions. Risc differs from traditional computer technology (Cisc, for complex instruction set computing) in a couple of important ways. First, the number of basic instructions in a Risc-based computer is less, and the instructions are hardwired rather than described in microprocessor microcode. Second, each instruction ideally takes only one clock cycle.

Risc machines inevitably fail to meet exactly these basic criteria. Commercial Risc architectures always include a few complex instructions that require more than one clock cycle. And, though instruction sets are reduced, they are not scaled back to "true" Risc levels. For instance, one manufacturer's chip includes 89 instructions, fewer than the 200-plus instructions in traditional computer architectures, but many more than the abbreviated sets of 30 or fewer instructions found in some research computers.

Compilers are the key to good performance in Risc computers. Compilers translate high-level programming of application programs into code that can be understood by microprocessors. Risc compilers must be able to organize instructions and data into a package requiring the smallest number of instructions to execute. Otherwise, the speed advantage of Risc is offset by the inefficiency of the compiler in translating the program into the fewest number of machine instructions.

Risc technology has a few drawbacks that require additional resources to solve. Because there are fewer complex instructions to handle mathematics, pure Risc processors often exhibit poor floating-point performance. Most Risc workstation vendors compensate for this by including a floating-point coprocessor on the CPU board. Also, Risc will not improve I/O performance; therefore, Risc computers must use memory-management units and large on-board cache to reduce the number of times main memory is accessed. Despite this, most new workstations use Risc processors quite successfully.



Risc architectures include integer units (IU) to perform basic processing, and floating-point units (FPU) for noninteger mathematics. These units may or may not be on a single chip. Memory-management units (MMU) and virtual-address cache are used to reduce calls to main memory.

hardware. For example, to draw a line between two points on a raster system the display processor must calculate which pixels fall along that line and activate them.

Graphics calculations may require vast processing power. For example, 1M byte of memory is required to support a screen with a resolution of 1,000 × 1,000 picture elements. A manipulation can be as simple as changing the color of one line or as complex as rotating the entire image. Color adds to the amount of information stored in memory.

Stored data used to fill a raster screen is called the bit-map. This map contains information needed to activate each pixel. The required size of the stored word depends on the number of colors displayed. A system that can display 16.8 million colors needs a 24-bit word format.

Speed is another important consideration in graphics displays. Some systems use dual processors, one for graphics and the other for input/output to gain speed. The graphics processor generates lines, arc, area fills, and performs other functions. Special-purpose graphics processors are often created as large-scale integrated circuits to further speed this function. Newer graphics chips allow users to model, manipulate, and edit complex solid models in near real time.

Another characteristic common to most workstations (and minicomputers and mainframes, for that matter) is a virtual-memory operating system. Operating systems perform basic housekeeping and permit other programs to run. Virtual-memory operating systems automatically swap portions of a program between main memory and disk storage. As a result, the computer can run large programs, essential in tasks such as finite-element analysis.

Larger computers

Most minicomputers have 32-bit processing power, so they can handle all but specialized CAD/CAM functions. Many CAD/CAM systems are still based on standard minicomputers, and a substantial amount of third-party software is available to perform sophisticated design, analysis, and related tasks on these computers. In addition, most minicomputers can support many interactive terminals, permitting widespread access to engineering and manufacturing databases. Minis generally have lower entry cost than mainframes or supercomputers.

Most vendors of minicomputers offer

HIGH-END GRAPHICS NOMENCLATURE

Here is some of the most widely used jargon associated with high-end graphic capabilities:

- **Aliasing** — The jagged lines that result from drawing on a raster screen. Most noticeable in low-res displays.
- **Antialiasing** — A technique that reduces the jaggedness of lines on raster screens. Usually involves displaying pixels between the line and the background at different intensities, thereby blurring the line slightly and diffusing the effect.
- **Attributes** — Qualities given to a particular primitive or segment. For example, the attributes of a point are its color and location, while the attributes of a line are its color, length, location, and orientation.
- **Bit blt** — Also known as a bit-block transfer. This is a raster operation that moves a block of bits from one part of the frame buffer to another. This is a quick way of moving a portion of an image around on the display screen.
- **Bit plane** — An array of memory wherein one bit corresponds to each pixel in the display. Frame buffers are generally referred to as containing one or more bit planes. For example, an 8-bit system has 8 bit planes.
- **Declutter** — Elimination of unwanted details in a display through select deletion of segments. Segment can be automatically added back to the display if the user zooms in on any particular area.
- **Display list** — A list of vectors, curves, pixel states, and text that defines the graphics data to be displayed. Moving this information to the terminal speeds response time.
- **Double buffering** — Display memory, generally known as frame buffers, is divided in two. One buffer stores the current display information, while the other creates the next view. The use of double buffering provides continuity and realism in animated sequences because it allows fast switching between views.
- **Frame buffer** — Memory that stores a full frame of picture data. There can be more than one bit of frame buffer memory assigned to each pixel. The more bits assigned to each pixel, the more complex the image that can be displayed.
- **Pixel** — Also known as picture element. It is the smallest portion of a display that can be addressed and given a color or intensity.
- **Primitives** — Basic elements of a graphics display such as points, lines, curves, polygons, and alphanumeric characters.
- **Projection algorithm** — A rule determining the angle at which visual structures are projected on a view plane.
- **Raster** — Basically, a grid of pixels that make up an image. Operations done on frame buffers are called raster ops. Raster scan data is what is used to control the intensity of the electron beam in the CRT monitor. Raster data is in contrast to vector data.
- **Real-image mode** — A display mode whereby specified elements are illuminated to create a pictorial image. This display mode is a derivative of raster displays, in which an array of elements on a screen is sequentially generated, row by row, much like the image on a conventional television.
- **Real-world coordinates** — Measurements expressed in the engineering units of the application.
- **Root segment** — Highest level segment in a view tree.
- **Segment** — Logical definition of a set of graphics elements that are displayed, transformed, erased, or manipulated as a unit.
- **Vector mode** — A vector, or stroke, mode of display used to generate line segments from pairs of specified endpoints. CAD drawings are usually displayed in this mode. Vector mode is usually implemented on raster systems through software that illuminates specified pixels lying along a prescribed line segment.
- **View plane** — The plane on which images are projected. This plane can be parallel to the display screen or tilted.
- **View volume** — The portion of a 3D model displayed at any point in time.
- **Z-buffer** — In 3D graphics, memory locations corresponding to pixels on the screen. But the Z-buffer contains data relating only to the depth axis of the image. Z-buffering is primarily used in hidden surface removal algorithms.

a range of processors, ranging from deskside units to so-called superminis that rival mainframes in speed and memory. With this "family" approach, firms can start using minis at a low entry cost and move up to more powerful (and more expensive) machines while using the same software.

Superminis with operating speeds of over 30 Mips are becoming increasingly important in CAD/CAM applications. These processors extend minis into the mainframe range but at a lower cost. The higher speed of superminis is made possible by application of high-speed integrated-circuit technology, most notably emitter-coupled logic (ECL).

Mainframes and larger

As you might expect, mainframes are used today in applications requiring substantial data processing and large memory capacity. These processors typically require room-size facilities that are air conditioned to maintain the proper operating temperature. Some mainframes are even cooled with refrigerant.

Originally, the only way to communicate with a computer was through punched cards, thus mainframes still support reading and punching of cards. Programs are run in a "batch" mode from beginning to end with no interactive interruptions possible. As a result, mainframes are often used to provide processing power after a problem has been set up with the aid of a microcomputer or mini. Moreover, mainframes are used to link together distributed smaller processors throughout a company. And microcomputers are often tied directly into mainframes so users can access a large database.

Supercomputers take advantage of the most recent advances in electronics, processing techniques, and memory organization to reach computing speeds many times that of mainframes. Typically, mainframes attain maximum processing speeds of a few megaflops (Mflops), a standard of measuring computing speed in million of floating-point operations per second. In contrast, a supercomputer can sustain an average rate of 20 Mflops over a range of problems and can achieve short bursts over 400 Mflops on well-structured tasks.

High speed comes at a high cost, however, with supercomputers costing in the millions. This price is offset by lower costs for CPU time. Complex problems in CAD/CAM that were once impractical to consider can now be solved economically. In addition, supercomputers can solve many problems so rapidly that several iterations can be performed to increase accuracy or evaluate alternatives.

Applications of supercomputers include solid modeling, kinematics, modal analysis, and fluid-flow simulations. Finite-element analysis is a candidate as well. Here, a supercomputer will perform tasks three to 10 times faster than a mainframe. But if the model is optimized to take advantage of a supercomputer's vector-processing capabilities, computation speeds can increase 100 times or more.

Supercomputers work faster because of data pipelining, high-speed circuits, and large internal memories. In pipelining, data elements stream through the processor in blocks instead of being handled one at a time. This function is accomplished with a vector-processing technique in which ordered groups of data elements called arrays or vectors are arranged in blocks of sequential memory locations. A few instructions then initiate the same operation on all elements of the vector, a much faster process than issuing a separate command for each data element.

Clock-cycle time, the fixed interval of time that controls the movement of data, is kept high in supercomputers through the use of special high-speed chips. These large-scale ICs tend to run hot, so coolant is pumped through the machines to remove several hundred kilowatts of waste heat.

One area of computer development today is near-supercomputers. These computers attempt to provide price/performance between minicomputers and supercomputers. Many companies

VECTOR VERSUS SCALAR PROCESSING

One feature that distinguishes supercomputing architectures from previous computer designs is the ability to perform data set, or vector, processing. That is, these machines can apply a single instruction to multiple data items (SIMD), whereas conventional computers apply a single instruction to a single data item (SISD). SISD is also known as scalar processing.

All computers perform instruction sequences, such as fetch and decode, compute operands, perform the operation, and store the results. Pipelining is a development that has improved the speed by which scalar machines perform these instructions. Pipelined architectures minimize execution time for a series of instructions by providing the necessary circuitry for each step in a separate functional processing unit within the CPU.

Pipelined units work as an electrical assembly line, with the first step of each new instruction beginning as soon as the first step of the preceding instruction is complete. Given an equation that calls for both multiply and add operations, a pipelined architecture can chain successive multiply and add operations together. So, the result of a multiply operation would be sent to the addition function unit for processing in the same clock cycle as the next multiply. Therefore, additions and multiplications are performed in parallel. As long as the pipeline is filled with operands, a new result can be output each clock cycle, even though several cycles are required to perform all steps on any set of operands.

The computer's control logic determines which mathematical circuits are required to perform any instruction, whether the required circuits are available, whether all previous steps of the instruction are complete, and whether results required from any previous computation are available.

Processing overhead can be eliminated by fetching and decoding an instruction once, then applying it to an entire array of numbers. A near-supercomputer provides vector registers that permit operation on up to 64 floating-point numbers of 64-bit lengths. When operating on arrays of more than 64 elements, the instruction fetch and decode is done for every 64-element block and once for any remainder.

Systems that use vector processing must have strong scalar-processing capabilities. Though vector processing offers significant time savings, all programs contain scalar operations. These include tasks such as calculating addresses, indexing arrays, and controlling loops. Even a mathematical loop involving only array operations requires a scalar count to control the number of times the equation is repeated. Thus, near-supercomputers must provide vector registers, high-memory bandwidth, and scalar facilities for fast access to stored values.

have developed near-supercomputers, which tend to utilize one-of-a-kind architectures.

One type of architecture used in these computers is called uniprocessor, where multiple subunits within a single processor handle different tasks. This approach works for a mix of scalar and vector operations. Another architectural approach uses numerous CPUs. This technique allows the user either to run several jobs simultaneously, or to divide up a single program and run parts of it simultaneously to gain performance. Yet another near-supercomputer architecture implements a very long instruction word. Whereas word length in most near-supercomputer architectures is 64 bit, very long instruction-word architectures may implement 1,024-bit word lengths. Increased word length allows several instructions to execute simultaneously.

Packaged systems

Ready-to-use graphics systems from turnkey vendors or value-added resellers (VARs) relieve users of the need to make software, hardware, and peripheral devices all work together, both before system installations and for the life of the product. The price of a turnkey system, however, is greater than the sum of the individual components. But the extra cost buys the assurance that the system works and that the vendor will provide support and service.

In the past, turnkey vendors often built or at least plugged together their own hardware. However, both the CAD/CAM industry and the computer industry at large have shifted emphasis to hardware platforms implementing various standards. Thus, many turnkey vendors now act primarily as system integrators, building applications and software interfaces around industry-standard hardware.

The typical turnkey CAD vendor supplies all necessary hardware, including workstations, digitizers or other data-entry devices, output equipment, and interconnecting cables. A typical CAD workstation might include graphic and alphanumeric displays, keyboard, graphic-input device, and a function-menu pad. The workstation might be built into a console or may come with special furniture on which to mount it. Printers, plotters, and other output equipment often sit in racks or other modular units.

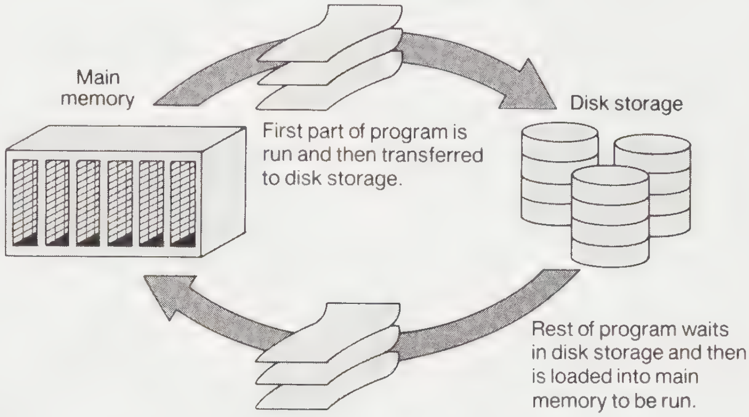
Turnkey vendors do not normally provide climate control or power-conditioning equipment. But most give buyers advice and guidance on purchasing and installing these items as well as provide guidance on other technical matters such as computer-room layout with which the buyer may be unfamiliar.

Software provided by turnkey vendors includes general-purpose programs and application software needed to operate the system. Software generally is delivered in object (working) form and not in source (modifiable) form.

It should be noted that most turnkey

VIRTUAL MEMORY EXPLAINED

Virtual memory techniques are an important tool used by workstations to provide ease of use. The concept of virtual memory can most easily be explained in terms of PCs. When choosing software to run on a PC under DOS, main memory size is almost always a constraint. Most packages specify that the PC contain a certain amount of memory to run the program. What causes this constraint is that the PC system software cannot run a program that contains more steps than there are locations in the PC main memory.


Main memory
Disk storage
First part of program is run and then transferred to disk storage.
Rest of program waits in disk storage and then is loaded into main memory to be run.

A PC can run programs that keep information in files that exceed main memory size. Adventure games are examples. The software brings in files stored on disk as the need arises. But the program itself is completely in main memory.

Larger computers have for years avoided this hindrance through use of virtual memory processors. These devices get their name from how the computer memory appears to the writer of a large program: The program never runs out of main memory space, making memory seem to be virtually unlimited.

The idea of virtual memory can be extended to the case where several programs are running on the machine at any given time. In general, each program is allotted a portion of the main computer memory according to some predefined scheme.

There are two basic ways of dividing computer memory in this manner. One is called segmenting, which divides memory into a number of segments that may each have a different size. Segment size can vary depending on the size of the program in the segment and on other factors. Processors in the 80X86 series use segmenting.

Another technique, called paging, divides memory into portions that are all the same size. Each of these portions is called a page frame, and each program running on the computer is allotted its own page frame. The 680X0 series processors can implement virtual memory using both segmenting and paging techniques.

To implement virtual memory, a memory manager circuit translates addresses in the application program, known as logical addresses, into physical addresses that exist on the machine. This mapping or translation process allows each program or task to be written without regard for where it will execute in memory.

Memory management circuits must also allow memory blocks to be shared by multiple tasks, as when two different programs need access to the same data. These circuits must also generate a signal when a program has tried to access data that does not currently reside in the main memory. The CPU, on receipt of this signal, takes the proper steps to suspend the task executing long enough to bring the needed information in from disk.

vendors avoid custom programming assignments. For example, they generally don't get involved with special-purpose programs to create families of parts. These are normally developed by users after the system is delivered. This type of software is not immediately essential but makes the system more convenient to use, or broadens capabilities.

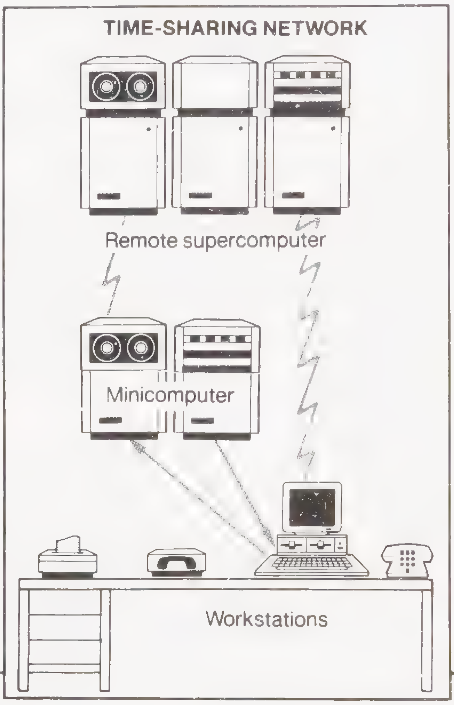
Services provided by a vendor based on its comprehensive CAD/CAM experience are a key advantage of a turnkey purchase, particularly for first-time users. These vendors provide a single, unambiguous focus of responsibility for CAD/CAM hardware, software, and applications. In addition, vendors offer education and consulting programs that cover system management and applications.

Turnkey services generally begin even before a buyer decides to purchase a system. For example, prior to making a proposal, the vendor studies the buyer's application, organization, and limitations to judge whether or not the system will do the job. Better vendors also determine if the buyer is willing and able to adjust its organization and operating procedures to make the system work.

Vendors also outline reasonable expectations of performance, benefits, payback, and service. Five basic types of services are generally provided in the turnkey package as part of the formal agreement: hardware maintenance, software maintenance, application assistance, management assistance, and education.

Time to time-share

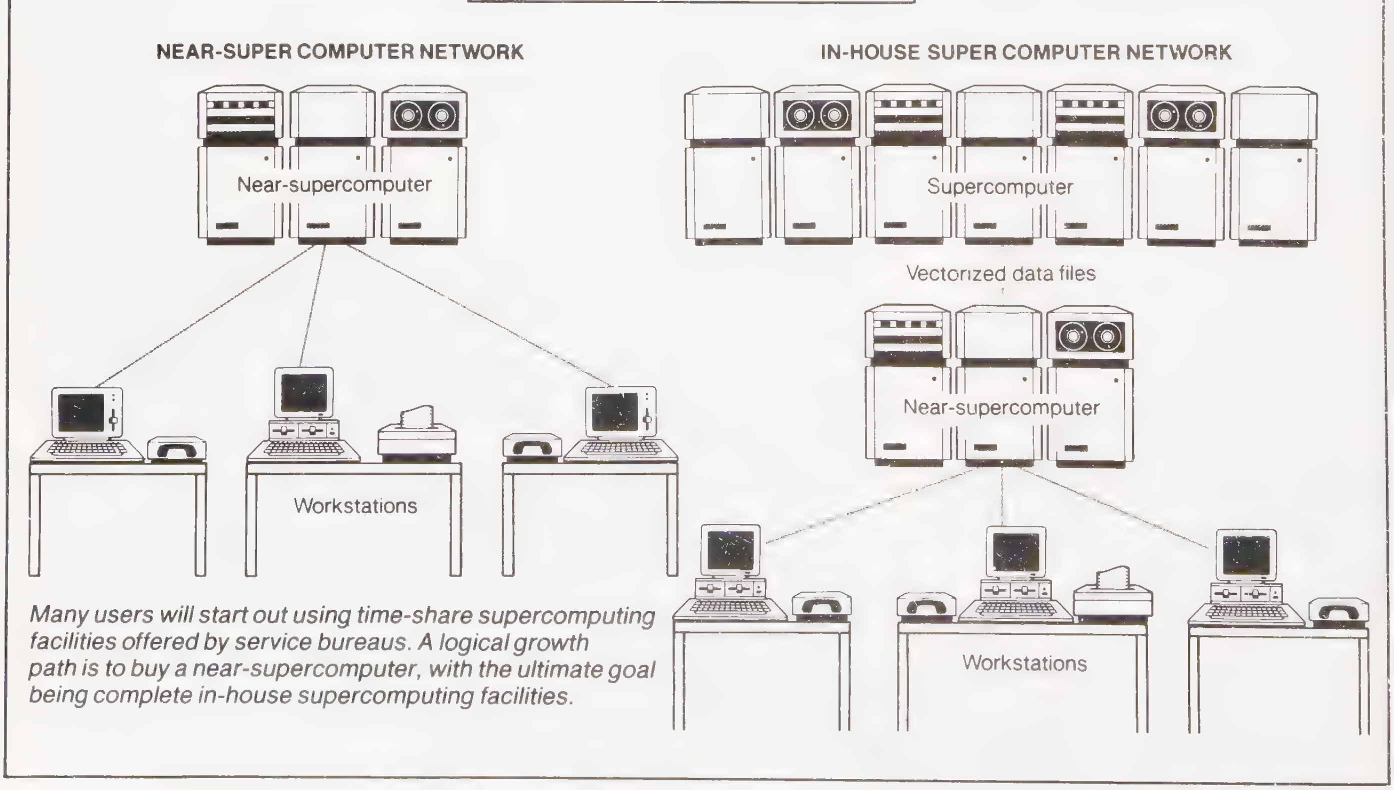
An alternative to owning a computer is time-sharing, which provides access to a mainframe or supercomputer. With this approach, the user's terminal connects by phone lines to a bank of remote computers at a service bureau. A customer basically pays only for the amount of computer processing time actually used. By spreading the costs of computing over many users, the time-sharing bureau can offer this remote computing at a fraction of the cost of owning an in-house mainframe or supercomputer.



Many service bureaus have specialized software packages that they continually refine and update. Some suppliers will even modify these programs or develop new packages for specific applications. Moreover, consulting services are generally provided to solve user-application problems.

Cost is the greatest single factor determining whether a company chooses time-sharing or in-house computing. Time-sharing is becoming more expensive than newer computer hardware. However, it is a means of easing into CAD/CAM. More frequent users of sophisticated analysis packages, however, may find time-sharing prohibitively expensive since heavy use can easily raise costs.

Part of the cost of time-sharing includes prearranged charges for training, software development, and consultation. The greatest part of time-sharing costs, however, is still computer time. In fact, these charges may be the only time-sharing costs for some well-established users who don't need equipment rental, consultation, or other peripheral services.



Many users will start out using time-share supercomputing facilities offered by service bureaus. A logical growth path is to buy a near-supercomputer, with the ultimate goal being complete in-house supercomputing facilities.

Larger time-sharing vendors have data-transmitting networks connecting the computer system with local offices in major cities via telephone lines. These networks let users connect to the computer by dialing up a local office and avoiding expensive long-distance charges. The network also permits the time-sharing bureau to route user data to alternate computer locations if equipment malfunctions or overloads. Time-sharing vendors also have sophisticated security precautions to prevent data tampering. ■

LOCAL-AREA NETWORKS

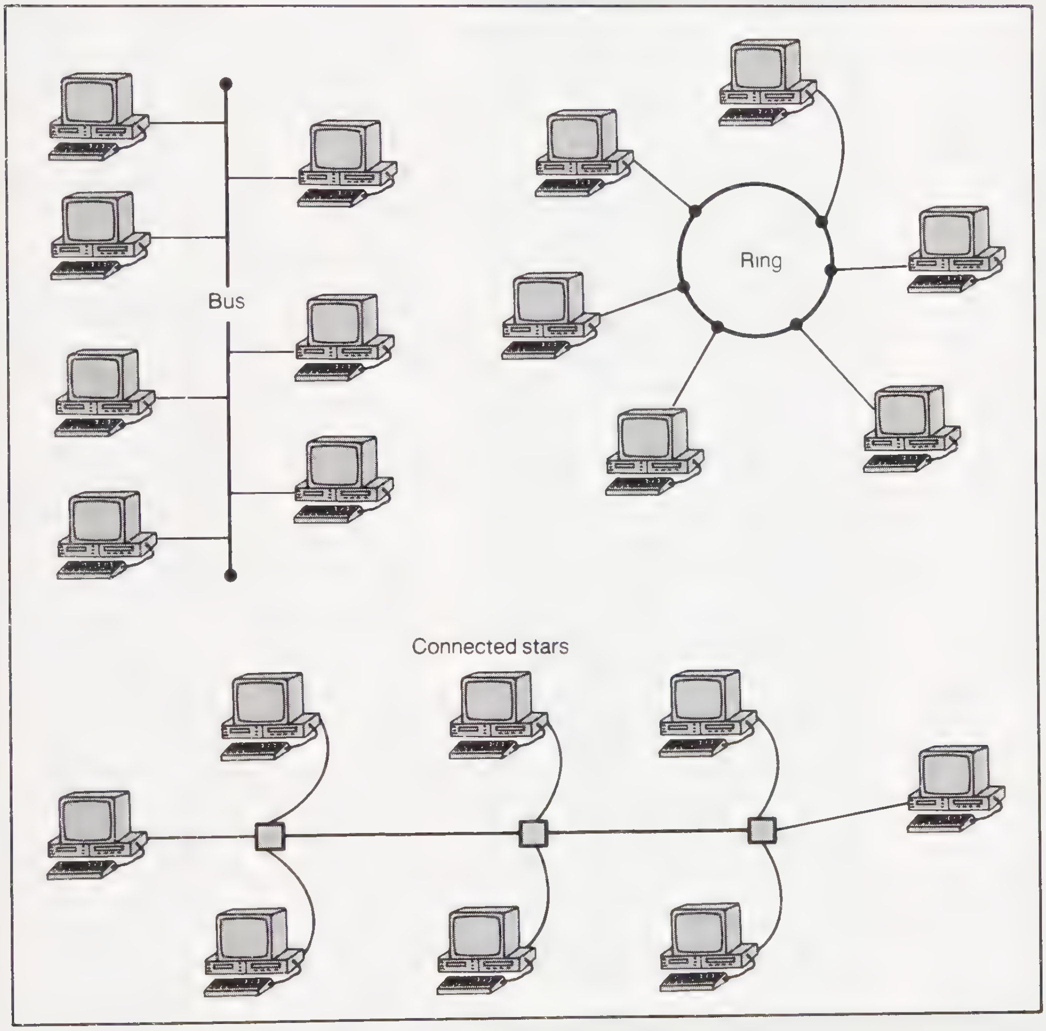
Workstations and PCs are increasingly interconnected within local-area networks (LANs). In networks, each workstation is given a node address. Workstations contain a communications program that permits sending and receiving data, which is grouped in packets for transmission around the network. Each packet contains the address of the sending and receiving nodes, either of which may request data transfer.

Three basic network types are currently in wide use. In the star configuration, a central master node controls the routing of data packets to peripheral slave nodes. Here, communication from one slave node to another always passes through the master node. Connected stars link machine clusters with a bus. In another configuration, nodes are connected in a ring where data passes serially (bucket-brigade fashion) around the network. In this way, all nodes monitor all data communication. In backbone or bus topology, machines can be connected in series without circling back to the master.

Several hundred nodes are theoretically possible on a LAN. However, systems usually have five to ten nodes, since increasing amounts of traffic can eventually saturate the network. For example, several stations simultaneously transmitting large engineering drawings (20,000 bytes each) can produce noticeable time delays even with the rapid data-communications rate of 120k bytes/sec.

Zero-slot networks connect PCs through RS-232 serial ports, with network control being done with software on the PC. Zero-slot networks are gaining popularity because of their relative low cost — often less than $150 per machine. However, top speed of these networks is limited to 115k bit/sec, compared with transfer rates of millions of bit/sec for media-sharing networks. The slow speed of zero-slot networks might make them suboptimum in applications where many graphic images or drawings transfer.

The speed of zero-slot networks is inversely proportional to the number of active users on the network. For example, a network with four PCs might take two minutes to transfer a 100k-byte file, if this is the only activity. If another user is trying to transfer another file simultaneously, over three minutes might be needed to move the same file. However, even the slower rate is acceptable for transferring files between users and peripherals. The ability to increase user convenience at relatively low cost is the greatest benefit of a zero-slot LAN.



Workstation and PC networks usually use one of three different cabling topologies: backbone, ring, or connected star. Because bus topology has two unconnected ends, it can connect machines in series, without circling back to the master. With connected stars, the PCs are joined at a hub, and the hubs are connected by a bus.

ANSYS REVISION 5.0

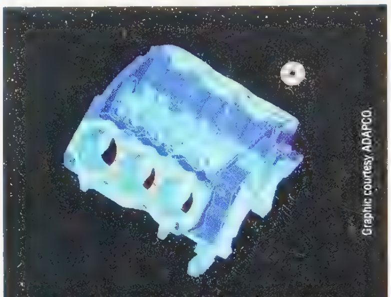
When It's Time to Get Serious About Finite Element Analysis

Your job depends on your ability to perform fast and accurate analyses. You need to think seriously about an engineering tool that will help you meet design requirements more quickly and profitably. When you're serious about finite element analysis, take a serious look at Revision 5.0, a major new release of the ANSYS program.

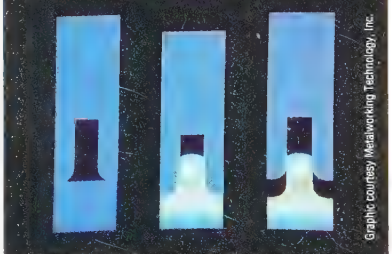
At Swanson Analysis Systems, Inc. (SASI), we realize that your design projects are becoming more varied and more complex. That's why we developed ANSYS Revision 5.0—to ensure you have access to the latest finite element technologies that will lead to better, more productive model-building, analysis, and results evaluation. Here are five good reasons why you should consider ANSYS Revision 5.0 for your finite element needs:

Comprehensive New Solid Modeling/Meshing Capabilities offer primitive and boolean operations that allow you to quickly and easily build your model. Solid modeling combines with other powerful ANSYS capabilities such as adaptive meshing and design optimization.

Complete Structural Nonlinearities Capabilities in the areas of contact surfaces and large strain address the increasing demand of FEA users since contact surfaces occur in most mechanical structural analyses, and large strain occurs in any metalforming analysis. Manufacturing processes such as pin insertion, impact and crash conditions, pressing, forging, stamping, rolling, or strip-rolling can be studied and improved.


Graphic courtesy ADAPCO.

Engine This contour display shows temperature distribution in a car engine block.


Graphic courtesy Metalworking Technology, Inc.

Rib Forging Large strain, contact surfaces, and viscoplasticity capabilities are shown.

Hair Dryer This solid model, using primitives and booleans, shows the new translucency capability.

Robust Design Optimization is a technique that generates a series of finite element designs to obtain an improved design. You define the criteria and bounds of the design and set up the model parametrically. The optimization routine then controls and executes the design cycles, deciding which new values to supply for the parameters to be used in each trial design. ANSYS design optimization permits virtually any aspect of a design to be optimized, and may be applied to any analysis.

Powerful New Graphics Capabilities, including 3-D volume visualization and annotation, help you to better understand your results and clearly present them to fellow engineers, management, and customers.

Integration With CAD Programs and Other Engineering Programs adds flexibility to your analyses by providing an efficient way to pass information between various types of design and analysis programs. SASI has made a commitment to work with major CAD vendors and customers in support of IGES and PDES/STEP as open standards for transferring data—SASI has chosen the open standard approach as opposed to another, vendor-specific option which locks you into proprietary interfaces. Also, for those of you who do computational fluid dynamics analyses, SASI offers an ANSYS/FLOTRAN® interface. You can build a single model using one common user interface and have access to fluid, structural, thermal, and magnetic analyses. All results can be evaluated using the same postprocessor.

There are at least 20 more good reasons to choose ANSYS Revision 5.0! To find out what they are, simply circle the number on the response card in this magazine, or call us at 1-800-WE-R-FEA1, and we'll send you a free pamphlet entitled, "25 Good Reasons Why You Should Choose ANSYS Revision 5.0."

ANSYS® FEA. Helping You Design a Better Tomorrow.™

ANSYS®
Swanson Analysis Systems, Inc.
Johnson Road, P.O. Box 65
Houston, PA 15342-0065
Phone: (412) 746-3304

Circle 543

Software for analysis and design

Recent developments, including easier modeling methods and improved analysis reliability, have made CAD/CAM less daunting.

Engineering software is today a critical component in the design lab. The most common type of engineering software is probably 2D drafting and design, if spreadsheets and related calculation packages are not categorized as engineering packages. There are a wide variety of drafting packages available. Many of these are moving to 3D features and solid modeling.

Drafting and drawing software

The user interfaces for many drawing packages all provide features and commands that have some commonality. All use a mouse or digitizer tablet as an input device for points, lines and other geometric features. Pull-down function menus are frequently used to put the system into different modes and to construct basic elements with minimal user input. For example, a rectangle can be defined by a corner point and its diagonal. Circles can be drawn in several methods, including center and radius, or specified by three points on the circumference.

Interactive graphics often show these elements before they are actually entered into the drawing file. A circle, for example, is displayed as soon as its center point is indicated. By moving the input device, the circle expands or contracts. When the circle is the correct size, it is entered by pushing a button on the input device.

Most drawing packages provide several ways to edit drawings. A line editor deletes lines or shows line lengths and angles. A point editor moves points, makes lines parallel, or makes a line intersect with another line, circle, or arc. "Undo" commands permit the last element or specific object to be deleted.

MECHANICAL CAE

In recent years, geometry-based programs aimed at helping engineers design have been lumped together under the title mechanical computer-aided engineering (MCAE). The term MCAE, however, is not well defined, and almost every software program focused at design engineers has been called MCAE.

Programs defined as MCAE actually fit into three categories and are useful in different design stages. One common thread among the programs is that they provide some way to analyze designs mathematically.

Conceptual design packages often are categorized as first-order MCAE products. These programs help engineers do preliminary design sketches and analysis. Most are 2D and based on variational, or dimension-driven, geometry. In dimension-driven software, geometry can be changed by changing dimensions. In traditional CAD software, geometry cannot be changed this way. Because these systems are 2D, they provide limited information about designs.

New 3D solid modelers coupled with analysis software provide a more detailed look at designs. They allow engineers to visualize, make changes to models, and do simplified structural or mechanical analysis.

These programs are easier to use than traditional solid modelers or analysis packages because they limit available options. For example, instead of offering 80 element types, these packages may offer less than 10. This means the software, though simpler to use, is not as versatile as a full-featured program.

Iterative, rule-based systems are meant to completely automate the design process. In these systems, the characteristics of a design are described in a symbolic programming language such as Lisp. Once design knowledge is captured in such a system, engineers can build parts and assemblies semiautomatically. They just enter the required specifications into the program and allow the system to do the design. The most difficult aspect of using these programs is describing the rules governing knowledge capture.

Categorizing design engineering software

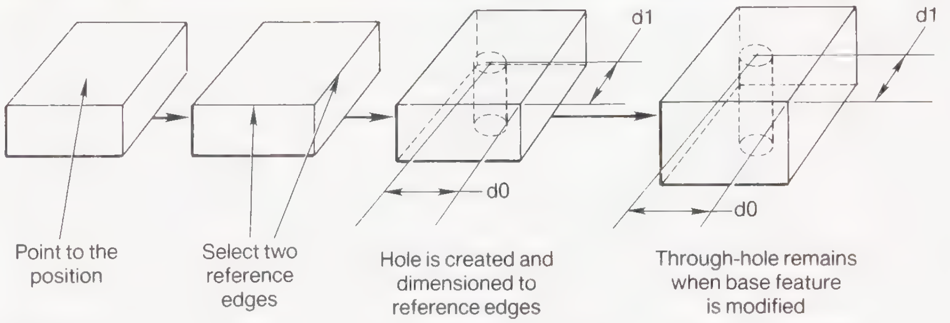
Products	Tasks	Examples
2D, Concept modeling	Preliminary design	Iconnex Premise
Workstation-based solids and analysis	Concept analysis	Aries Integraph's I/EMS PDA'sP/Concept ICAD
Geometry-based expert systems	Semi-custom, iterative work	Wisdom systems
Traditional CAD	Drafting and detailed design	CADAM Intergraph drafting
Traditional solids and analysis	Verification	Patran MSC/Nastran SDRC Geomod Ansys ATP NC
CAD/CIM	Prototyping, testing, NC	Anvil 5000

In MCAE, two-dimensional concept design packages fit at the beginning. Solids-based workstation software fits in just prior to detail design. Expert system-based, iterative design systems, when appropriate for semicustom work, also fit in the period just prior to detail design. Traditional solid-modeling and analysis programs usually fit between detailing and prototyping. They have been used primarily to verify designs, rather than conceptualize them.

EXPLAINING PARAMETRICS AND SOLIDS

Solid models are complete, unambiguous representations of parts, but they do not capture engineering knowledge. Furthermore, a solid model may be difficult to modify.

Parametric, or dimension-driven, CAD allows the user to define a part in terms of parameters instead of exact solid geometry. Parameters carry information about relationships between dimensions, design intent, and manufacturing constraints. Solid geometry is then derived from this information. An engineer can make interactive changes to any of the design parameters at any time in the evolution of the design model, and allow the parametric system to regenerate the solid geometry and other outputs, such as detail drawings. The biggest drawback of some parametric modelers is they can represent only relatively simple parts.


d1
d1
d0
d0
Point to the position
Select two reference edges
Hole is created and dimensioned to reference edges
Through-hole remains when base feature is modified

Once defined, basic features can be modified without changing all solid geometry. The terms d1 and d0 refer to parameters that define the basic relationship between the feature and the model.

Zooming comprises another important function for looking at a specific area on the drawing in greater detail. This function can be controlled in several ways, including a percentage of zoom or zoom inside a window. A drawing can also be moved horizontally or vertically by a "panning" function. This, too, is controlled in several ways. The pan may cover a specific length, or be defined by a line drawn on the CRT showing the length and angle of pan.

Equally spaced grid points can be displayed on the screen as a drawing aid. Usually, the grid spacing is defined by the user. A related function, called Snap, allows entered lines to "snap" to the nearest grid point. The snap can be turned on or off, depending on what the operator is doing.

Drawn objects can be moved or "dragged" on the screen during editing. A copy function also permits an object to be copied anywhere else in the drawing. Most systems also allow the user to define symbols and put them in the drawing when needed. So-called symbol libraries can be purchased for certain applications such as piping or interior design. Such a file can contain hundreds of predefined objects that can be called up and placed in the drawing.

Some systems also automate much of the dimensioning required for the drawing. Through menu commands, the user can have the system compute and display distances or angles in appropriate locations. Dimensions usually are not associated with geometry. In associative systems, however, changing geometry will change the dimension automatically. Parametric systems allow users to change geometry by making dimension changes.

Several fonts typically are available for placing text on drawings. Characters can be displayed in a range of sizes and angles. The text may be centered or justified right or left and even be positioned on an irregular curve or angle. Text is located by defining a single point on the drawing.

In layering, the drawing is split into several distinct overlays to help keep various features straight. This function helps simplify creation of the drawing and makes plotting easier because separate layers can be easily plotted in different colors. Layers can also be plotted separately to automatically generate a variety of drawings. For example, printed-circuit boards can be plotted in layers for holes, circuits, and components.

Some systems automatically generate separate layers for elements such as dimensions. Newer systems may not use layers *per se*, but allow users to group geometric elements and turn these elements on and off as required.

The ability to develop wire-frame models is a feature becoming more and more common in drafting packages. Wire-frame models represent 3D part shapes with interconnected line elements. Also called edge-vertex or stick-figure models, wire frames are the simplest 3D geometric representation, though not the easiest to create.

More advanced techniques, such as solid modeling, have evolved out of wire-frame modeling. However, wire-frame models use little computer time and memory, and provide precise information about the location of surface discontinuities on the part.

Wire frames, however, contain no information about the surfaces themselves nor do they differentiate between the inside and outside of objects. Thus, wire frames can be ambiguous in representing complex physical structures and often leave much interpretation to users.

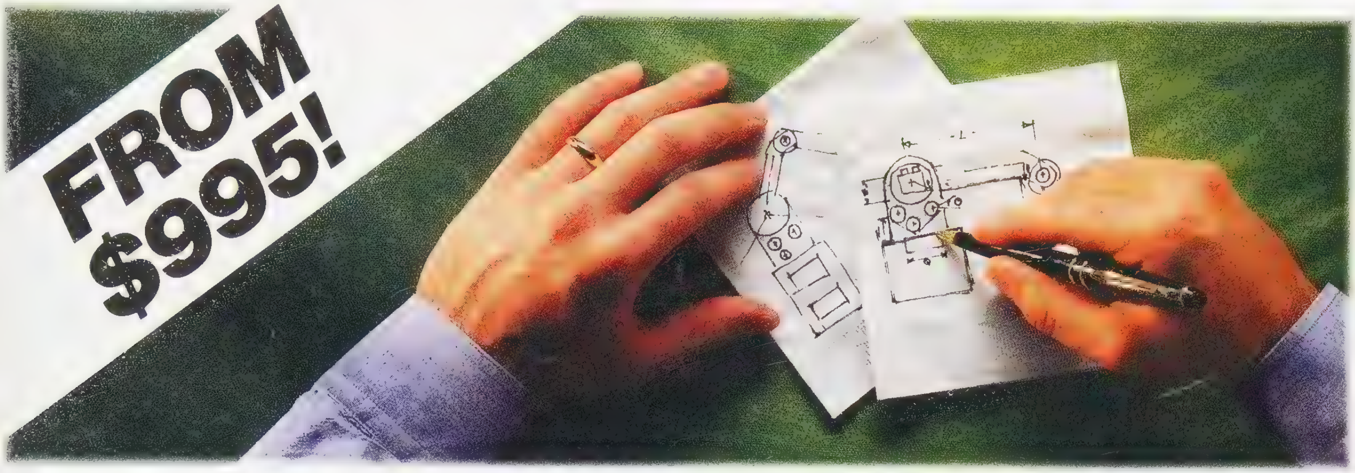
Wire-frame models are created by specifying points and lines in space. To create the model, the CRT screen is usually divided into sections showing various model views. Some systems use only a single view with a movable workplace on which points and lines lie.

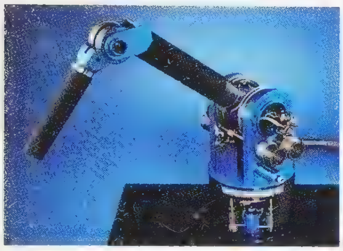
Designers draw lines on the CRT in much the same manner as a drawing board to create top, bottom, side, isometric, and other views of the model. The designer need not manually draw each line in a wire frame. Rather, the CAD system constructs the lines based on user-specified points and commands chosen from an instruction menu.

In CAD, most wire-frame models generally consist only of straight lines. To generate a line, the user may designate two end points and give the computer a LINE command. Or a line may be automatically produced parallel or perpendicular to another line or tangent to a curve. Some CAD systems produce straight-line elements with up to 40 such techniques.

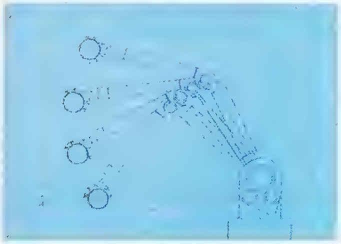
An analogous set of features can also

Finally. The freedom to design.





This robot arm, developed for the NASA space station, can safely grasp fragile objects and sense its way around obstacles.



DesignView software enabled engineers to simulate and optimize performance long before the arm was manufactured.

DesignView® software is an exciting new CAD package developed expressly for engineers. It's a 2-D sketcher, parametric design package, and analytic equation solver all in one. DesignView software provides complete design freedom, enabling you to think, experiment, and consider "what if."

■ **Sketch ideas quickly and easily.** Capture your initial idea by sketching the basic shape of a design. As you input dimensions, the software automatically reshapes the geometry. An intelligent user interface provides dynamic graphical feedback and speeds you through the process.

■ **Adhere to design criteria. Guaranteed.** Specify known values, conditions, and relationships explicitly or by calling upon an optional library of mathematical equations and formulas. Constrain a part, animate an assembly, or simulate the product life cycle. You can even link your design to Microsoft® Excel™ or Lotus 1-2-3® spreadsheets.

■ **Explore "what if."** With DesignView software, all aspects of the design are interwoven. You can affect the design by modifying geometry, changing variable and dimension values, or altering equations. So, it's a snap to experiment with design alternatives while adhering to the original design intent.

■ **Generate clean, unambiguous drawings.** DesignView software lets you clearly communicate design intent to other departments or divisions. Intelligent notes, associative multiple views, dimensions, tolerances, and more lead to exceptionally clear designs.

■ **Complement your existing CAD capability.** DesignView software works well with your existing CAD drafting software. It fosters engineering creativity and improves communication between engineers and the rest of the product development team.

DesignView software runs on MS-DOS® PCs utilizing the Microsoft® Windows™ interface. A UNIX® version is also available. If you want better designed products in less time, then give DesignView software a try!

Computervision Corporation
100 Crosby Drive, Bedford, MA 01730
Telephone: (800) 248-7728 (U.S. except MA)
(617) 275-1800, ext. 4594
FAX: (617) 271-0015

COMPUTERVISION

DesignView® 3.0

Robotic arm photography and geometry courtesy of Barrett Technology, Inc., Cambridge, MA.

COMPUTERVISION, the Computervision logo, and DesignView are registered trademarks of Computervision Corporation, a subsidiary of Prime Computer, Inc. Microsoft and MS-DOS are registered trademarks and Excel and Windows are trademarks of Microsoft Corporation. Lotus 1-2-3 is a registered trademark of Lotus Development Corporation. UNIX is a registered trademark of AT&T

Circle 544

The right tool for the job.

Having the right tool, like brake spring pliers or an oil filter wrench, can turn a potentially frustrating job . . . into one that is manageable and enjoyable. If your job is mechanical design, then the right tool for the job is Personal Designer® software. It provides the right combination of CAD capabilities including: ■ Comprehensive 2-D Drafting/Detailing ■ True 3-D Modeling ■ Hidden Line Removal ■ Bezier and NURB Surfaces ■ Faceted and Smooth Shaded Pictures.

With Personal Designer software, you're equipped to tackle challenging mechanical design problems. Build sizeable models (up to 64,000 entities) with complete associativity. Change the part, and all drawings, dimensions, crosshatching, and multiple views update automatically. Create drawings to ANSI, ISO, and JIS standards. Customize the user interface. And exchange data with other CAD packages via IGES or DXF.™

There's a lot more. You can fillet, sweep, and intersect complex surface geometry, and take advantage of software options for project management (PDex) and integrated 2½- and 3-axis NC programming (Personal Machinist®). To further expand your horizons, utilize the hundreds of available third party offerings. And draw on the expertise of Computervision's worldwide network of VARs.

There's a direct translator available, too. So, should you ever need Computervision's top-of-the-line CADDS® software, you can take Personal Designer data bases with you.

The bottom line: Personal Designer software is a smart buy in today's crowded marketplace. It's available for 386/486 PCs as well as the SPARCstation® workstation. And prices for 2D start at $1,995.

Get the right tool for the job, from the company that pioneered CAD/CAM.

Computervision Corporation
Personal CAD/CAM Business Unit
100 Crosby Drive, Bedford, MA 01730
Telephone (800) 248-7728 (U.S. except MA)
(617) 275-1800, ext. 4594 FAX (617) 271-0015

COMPUTERVISION
A Prime Company

PERSONAL
cad
cam
PRODUCTS

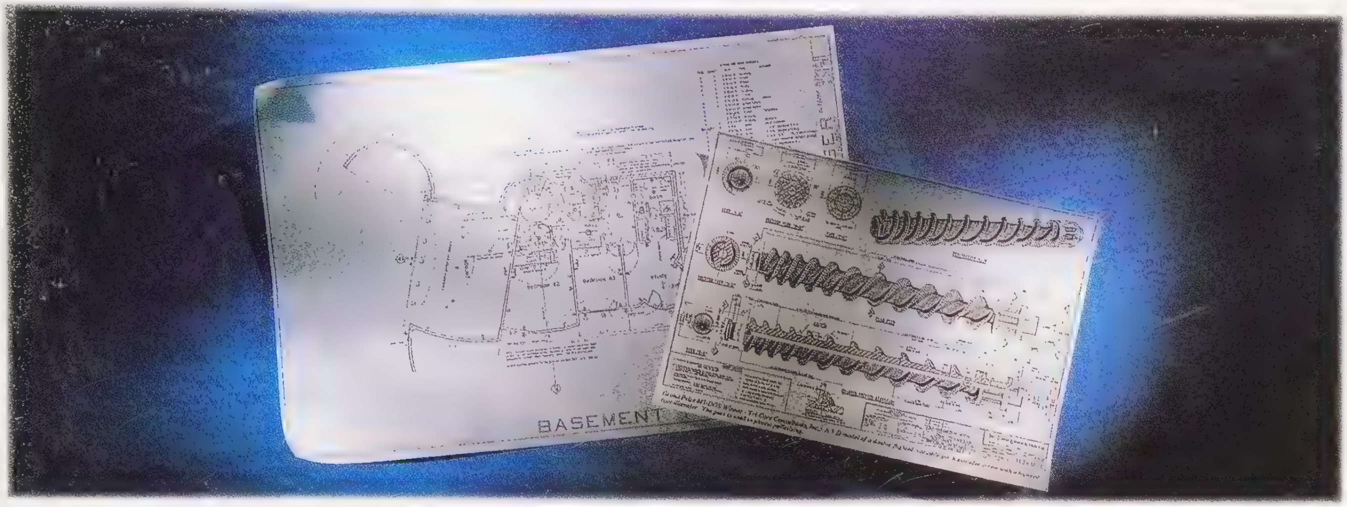
Personal Designer® 5.0

Part database courtesy of American Tool and Mold, Inc., St. Joseph, MI.

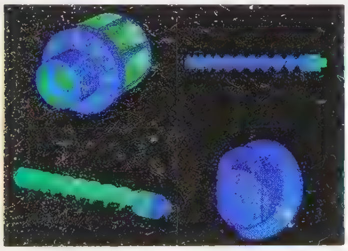
COMPUTERVISION, the Computervision logo, Personal Designer, Personal Machinist, and CADDS are registered trademarks of Computervision Corporation, a subsidiary of Prime Computer, Inc.
DXF is a trademark of Autodesk, Inc. SPARCstation is a registered trademark of Sun Microsystems, Inc.

Circle 545

If drafting is what you do, then VersaCAD® software is what you need.



This multi-level California home spans 4,000 square feet.



More than 12,000 surfaces and 7,000 points were used to define this extruder screw.

VersaCAD software from Computervision produces high quality engineering drawings FAST. If drafting is what you do, this is the package for you.

- **Unparalleled versatility.** Whether you're an architect, civil engineer, or mechanical designer, VersaCAD software can help. It's used daily in industries and applications from A to Z.
- **Simple enough to learn in a day.** You need to be productive with a CAD package from day one. With VersaCAD software, you can be. And once you learn it, you'll never forget it.
- **Sophisticated enough for demanding projects.** It may be simple to use, but VersaCAD software is solving complex engineering problems. Customers have used it to design everything from individual components to complex mechanical assemblies, from private homes to corporate headquarters, from interior and landscape designs to utility maps. Call for our latest brochure which showcases actual customer projects.
- **Premier drafting capability.** VersaCAD software has the drafting and dimensioning features you'd expect, and then some. Alter geometry and dimensions update automatically, and vice versa. Project isometric views from orthographic views automatically. Insert a symbol into an object, such as a wall, and the geometry cuts back automatically. VersaCAD software shines in 2D, and with its 3-D visualization options you can put together eye-catching presentations.
- **Large pool of experienced users.** 80,000 users and 1,000,000 students know VersaCAD software, so you have lots of expertise to draw upon.
- **DOS,® UNIX,® and MAC.®** Chances are that you can run VersaCAD software on the hardware that you already have.
- **Priced from $595.** If you're looking for leading edge drafting software that delivers a lot of value for the money, VersaCAD software is the intelligent choice.

Computervision Corporation
Personal CAD/CAM Business Unit
100 Crosby Drive, Bedford, MA 01730
Telephone (800) 248-7728 (U.S. except MA)
(617) 275-1800, ext. 4594
FAX (617) 271-0015

COMPUTERVISION
A Prime Company

PERSONAL cad cam PRODUCTS

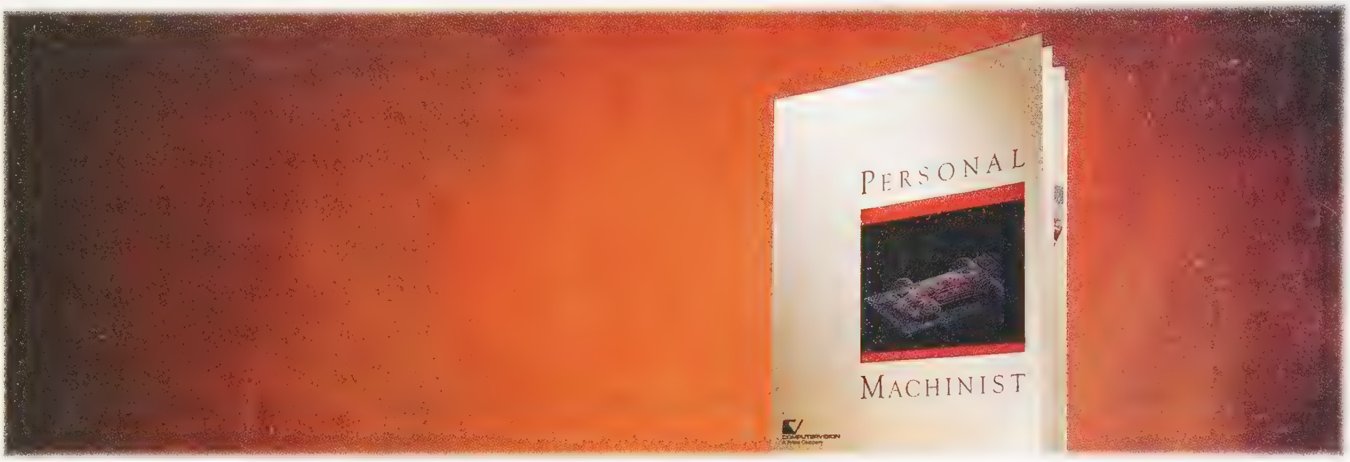
VersaCAD®

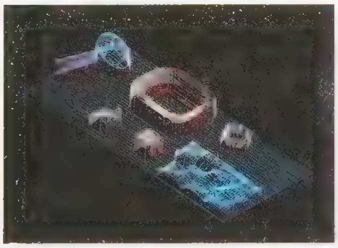
Private residence database courtesy of James Statser, architect, Olivenhain, CA; Extruder database courtesy of Tri-Core Consultants Inc., Hoffman Estates, IL.

COMPUTERVISION, and the Computervision logo are registered trademarks of Computervision Corporation, a subsidiary of Prime Computer, Inc. VersaCAD is a registered trademark of Versacad Corporation, a subsidiary of Prime Computer, Inc. MS-DOS is a registered trademark of Microsoft Corporation. UNIX is a registered trademark of AT&T. Apple and Macintosh are registered trademarks of Apple Computer Co.

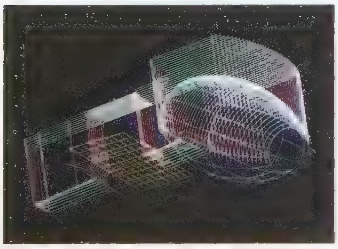
Circle 546

The booklet is free. Choosing the wrong CAM software is costly.





Program a single tool path for up to 1,000 surfaces on a PC.



Machining options include unidirectional cutting, containment surfaces, and horizon line machining.

That's why you need to take a look at the NEW Personal Machinist® software from Computervision.® It's been re-engineered from the ground up, and sets new standards for CAM performance.

▪ **A modular approach.** For starters, Personal Machinist software is totally modular. Start with the 2½ axis module. As your needs grow, add the 3-axis module for surface machining. 4- and 5-axis modules are on the way, too. Once you've learned one module, you're well on your way to mastering them all because the user interface is consistent throughout. You're dealing with a single part database, too, with no translation required.

▪ **Best of class.** Personal Machinist software is the fastest and easiest to use CAM software in its class. Period. You don't have to be a computer expert. Selections are made from on-screen menus and prompts. Part geometry and tooling are displayed in full 3 D and can be examined from multiple views simultaneously. A dynamic tool display lets you preview machining operations. And the software performance is turning heads. Jobs normally expected to take hours can often be completed in minutes.

▪ **Your CAD package or ours.** If you use Computervision's Personal Designer® CAD software, you can add Personal Machinist software at any time, building NC toolpaths on top of the SAME part database. If you use another CAD package, there's a version of Personal Machinist software for you, too.

▪ **Write your own posts.** A universal post processor generator is included at no extra charge. Write posts for virtually any CNC machine by going through a simple on-screen question and answer session. Direct Numerical Control (DNC) utilities are included, too.

▪ **Prices start at $4700.** Personal Machinist software is available for MS-DOS® PCs and the Sun® SPARCstation® workstation. With prices starting at $4700, run, don't walk, to your nearest Computervision reseller. The future of CAM is here, and Computervision has it!

Computervision Corporation
Personal CAD/CAM Business Unit
100 Crosby Drive, Bedford, MA 01730
Telephone (800) 248-7728 (U.S. except MA)
(617) 275-1800, ext. 4594
FAX (617) 271-0015

MACHINE DESIGN
LEADER AWARD
WINNER
CAD/CAM

COMPUTERVISION
A Prime Company

PERSONAL
cad cam
PRODUCTS

Personal Machinist

COMPUTERVISION, the Computervision logo, Personal Designer, and Personal Machinist are registered trademarks of Computervision Corporation, a subsidiary of Prime Computer, Inc. MS-DOS is a registered trademark of Microsoft Corporation. Sun and SPARCstation are registered trademarks of Sun Microsystems, Inc.

Circle 547

produce curved lines. Circles may be produced by a specifying point and a radius, three points on a circumference, or tangent points to two or three other curves. And conics — complex curves such as ellipses, hyperbolas, and parabolas — may be produced by specifying appropriate points. Most CAD systems can also generate splines — smooth, continuous curves fit through a series of arbitrary points specified by the user.

More sophisticated drawing packages contain a variety of additional modeling aids. For example, points and lines created in one view may be automatically projected in other views. And once specific details have been modeled, the system can duplicate them repeatedly at specified locations on the model.

In some systems, individual lines can be deleted from the model at any time. Moreover, in working the complex models, users can temporarily erase selected lines from the screen without deleting them from the model to view more clearly the area under construction. Erased lines can be recalled to the screen at any time. Likewise, certain model areas may be enlarged and later reduced. After completing a model, users may blank out hidden lines to give the model a solid appearance.

One factor to keep in mind, however, is that not all models that look like 3D wire frames are wire-frame models. Some PC software allows users to build isometric models that appear to have Z-axis depth, but in reality do not. These systems are usually called 2¼D systems.

Advanced modeling

Geometric models are frequently thought of as being either surface or solid models. But actually, wire-frame models are the simplest form of geometric model. Many ambiguities of wire-frame models are overcome with surface models, which define the outside part geometries precisely and help produce NC machining instructions where the definition of structure boundaries is critical. However, surface models represent only an envelope of part geometry, even though features such as automatic hidden-line removal make the model appear as a solid.

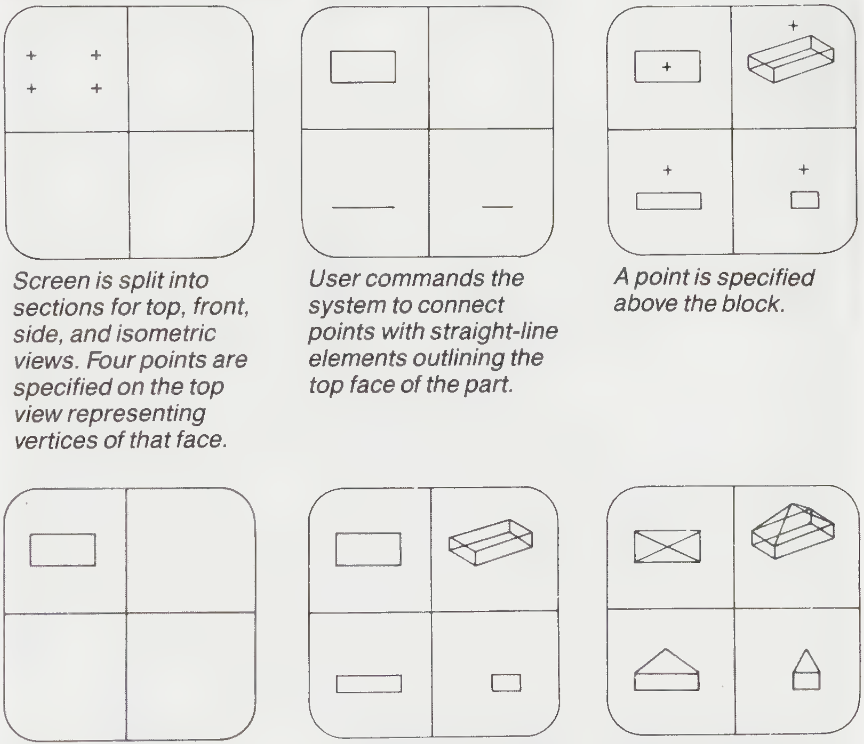
The way to construct surface models is by connecting various types of surface elements to user-specified lines. The entire model may be comprised of different types of interconnected surfaces. With surface modeling, however, an entire structure may provide more detail than necessary for many applications, so some models combine surfaces for detailed faces, with wire frames representing the rest of the part.

Full-blown CAD systems give extensive surface menus for modeling purposes. Typical surface menus include planes, tabulated cylinders, ruled surfaces, and surfaces of revolution, along with sweep, fillet, and sculptured surfaces. The plane is the most basic surface type. The system merely creates a flat plane between two user-specified straight lines. A tabulated cylinder is the projection of a free-form curve into the third dimension.

An operator constructs a ruled surface by starting with two different edge curves. The effect is a surface generated by moving a straight line through space with the end points resting on the edge curves. A surface of revolution is created by revolving an arbitrary curve in a circle about an axis. This capability is especially useful in modeling turned parts and parts with axial symmetry. The sweep surface is an extension of the surface of revolution. Sweep surfaces, however, sweep an arbitrary curve through another arbitrary curve instead of a circle.

Filleting uses a cylindrical surface that connects two other surfaces in a smooth transition. This is a tedious, subjective operation that has been done manually for years. But CAD systems solve the problem of blending surfaces with the precise mathematical continuity required by many applications.

WIRE-FRAME MODELING



Screen is split into sections for top, front, side, and isometric views. Four points are specified on the top view representing vertices of that face.

User commands the system to connect points with straight-line elements outlining the top face of the part.

A point is specified above the block.

User commands the system to project the image into the other three views.

Face is projected into the second dimension, producing a rectangular block.

User commands the system to connect the point to the top corners of the block, creating a pyramid. Model is complete.

In this sequence of pictures, a wire-frame model is created on the terminal display of a typical CAD system. Of course, step-by-step procedures for creating models differ from this generalized representation according to system capabilities and the individual technique of the user.

Many systems use a split-screen approach, as shown here, in which multiple views are displayed and manipulated simultaneously. And some systems use a single trimetric model view with working planes specified for each operation. However, these are merely different ways of pictorially displaying the actual 3D geometric model.

The term used to signify complex curved surfaces is sculptured surface. There are many types of sculptured surfaces, including curve-mesh, free-form, B-spline, and cubic-patch surfaces. A sculptured surface is a differential surface created from two families of curves. These families are not restricted to being orthogonal, nor are the curve types fixed. Curves need not even be parallel. The two curve families intersect one another in crisscross fashion, creating a network of interconnected patches.

The complex contours of sculptured surfaces cannot be described with the usual lines and curves of conventional modeling. Typical structures containing such contours range from helicopter blades and automobile bodies to camera cases and glass bottles.

Solid models have the advantage of being an unambiguous way to define geometry and volume, providing the ultimate way to describe mechanical parts in the computer. Unlike wireframe or surface modeling, solid models provide the accuracy needed for precise mechanical design. And, solid models hold the potential to create a database that provides a complete description of the part for more accurate analysis.

The typical use for solid models has been primarily as a means of calculating mass properties, simulating operation of critical components, and to create realistic images. Although these applications represent great leaps over manual design, they are only a hint of the benefits that can be had by using solid models.

Solid models are constructed either with primitives or with boundary definitions. Both methods employ successive combinations of simple geometric operations to develop complex geometries.

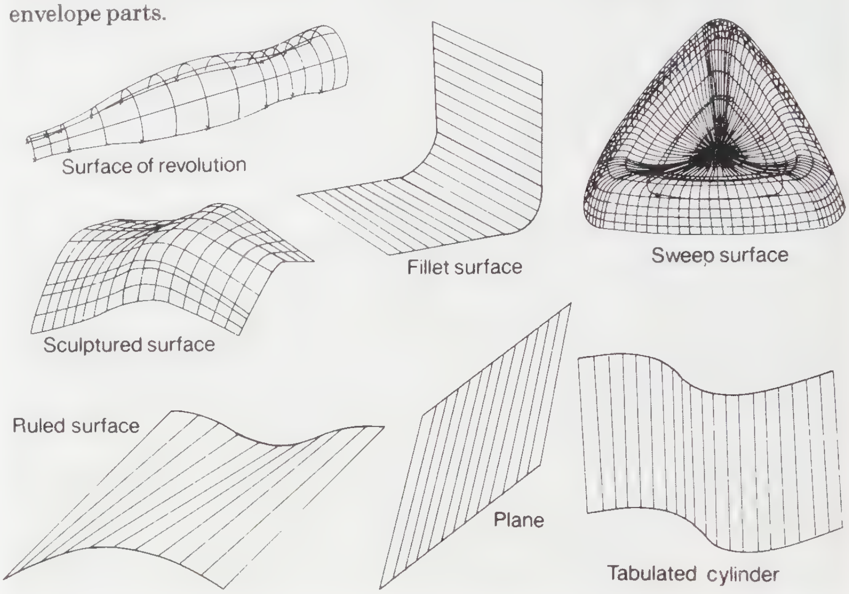
The Constructive Solid Geometry (CSG) method, or primitive approach, allows elementary shapes such as blocks and cylinders to be combined in building-block fashion. The user positions these primitives as required and then creates a new shape with the proper Boolean logic command (union, difference, or intersection).

The boundary definition technique employs two-dimensional surfaces swept through space to trace out volumes. A linear sweep translates the surface in a straight line to produce an extruded volume. A rotational sweep produces a part with axial symmetry, while a compound sweep moves a surface through a specified curve to generate a more complex solid. Another boundary construction technique called gluing joins two previously created solids with a common surface.

CSG and boundary methods are each best suited to a particular class of shapes. Most industrial parts, for example, consist of planar, cylindrical, or other simple shapes and are readily modeled with primitives. But components with complex contours, such as automobile exhaust manifolds and turbine blades, are more easily modeled by boundary definition. Because the two

SURFACE TYPES

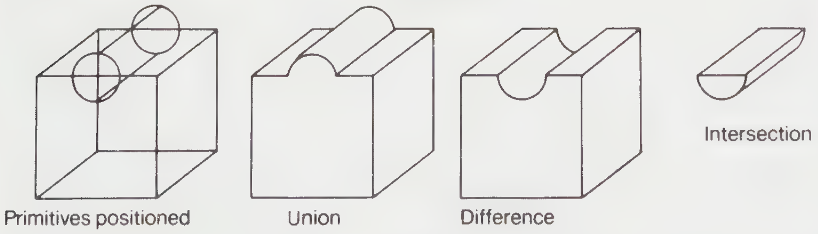
Surfaces available for geometric modeling range from simple planes to complex sculptured surfaces. These surfaces usually are represented as a set of ruled lines. However, the computer recognizes these lines as continuous surfaces. Users select surface types from a menu to model individual details or fully envelope parts.



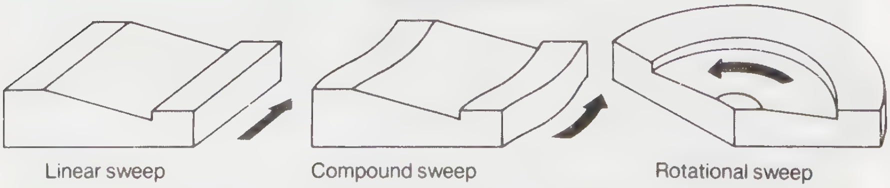
CSG, BOUNDARY OPERATORS

Solid models can be built with either primitives or boundary representations. Many system offer both methods. In the primitive approach, elementary shapes are combined in a building-block fashion to create a new shape. So-called Boolean logic commands, such as union, difference, and intersection, aid in forming new shapes. With boundary definition, 2D surfaces are swept through space to trace out volumes. Most systems offer several types of sweeps to help create a variety of shapes.

BOOLEAN



SWEPT VOLUMES



What a racket!

$ 3,000 bucks for a CAD program? Are you kidding?

DesignCAD 2D is only $349, and it has more and better features than the other CAD programs that cost $3,000!

And, if you're ready for a three dimensional CAD program, there is the state-of-the-art DesignCAD 3D . . . for only $499!

DesignCAD is the software used in the design of Andre Agassi's tennis rackets, the Patriot missile, and scores of other high tech, low tech, and no tech products.

So what's all the racket about? It's because we believe that it's silly to spend more on a CAD system than you would on a word processor. Agree? Well, the ball's in your court.

Your product designed with DesignCAD? Let us know, and maybe we'll put it in one of our ads.

For a *free* demo disk
and 16 page color brochure,
contact:

American
Small Business Computers, Inc.
One American Way• Pryor, Oklahoma 74361
(918) 825-4844• FAX (918) 825-6359

European Headquarters:
102 Rue La Fontaine• 75016 Paris, France
Phone 331 4520 6540• FAX 331 4520 6539

Other offices in:
Athens • Barcelona • Brussels • Bucharest • Istanbul • London
Mexico City • Paris • Prague • Sao Paulo • Tokyo • Warsaw

Buyers Assurance Seal

Computer Shopper Best Buy of 1991
CAD/CAM Software

PC Magazine Editors' Choice

PC Magazine Editors' Choice

Circle 548

FEA MADE EASY

Finite-element analyses take place in a series of steps which often happen simultaneously and transparently in the computer. Engineers must intervene in some steps to provide data.

Model the design. Engineers divide the continuum or field into an equivalent system of elements with associated nodes. Sometimes, an idealized 2D finite-element model is made to represent a 3D design. Engineers also choose elements, which requires sound engineering judgment about the design being studied. The most common element types are beams, trusses, plates, shells, 2D quadrilaterals, and bricks. Engineers specify loads after the model is developed.

Select the element nodal variable function. A function that will solve for unknown variables, d, within each element is specified, depending on the type of problem being analyzed. For example, for an elasticity problem, the function will find displacement; if the problem is heat transfer, the function determines temperature gradients. Similarly, in fluid mechanics the function finds flow velocity, while in magnetics it determines scalar or vector potential.

Set up element derivatives and constitutive relationships. Element derivative equations describe physical behavior at specific points. In structural analysis, for example, the derivatives of displacement measure strains. In heat transfer, on the other hand, the derivatives of temperature (gradients) measure heat flow. In constitutive relationships, material properties are taken into account. In structural analysis, a set of material coefficients, k, relate strains to stresses produced. Constitutive relationships often are described with standard equations. For example, Hooke's Law describes the constitutive relationships for uniaxial pull on a bar.

Derive the stiffness matrix. The stiffness matrix for each element is determined from the set of stiffness coefficients. In structures and fluids, this matrix includes material property and geometric data. In heat transfer, it contains information on conductivity, while in magnetics the data refers to permeability. The element matrices are assembled into a global stiffness matrix, K.

Assemble the element equations and add boundary conditions. The individual equations for each element are reduced to a single set of simultaneous equations. This set is reduced and represented by a single equation in matrix notation $\{F\} = \{K\}\{d\}$, solve for d, where F = applied forces or loads. The equation is modified to include boundary conditions.

Solve for element nodal variables. The three most prevalent methods used by programs to solve the equations developed by the finite-element program are:

- Invert the stiffness matrix. This method is useful only for small-size problems.
- Direct solution of the set of equations. A typical direct solution is Gauss elimination. In this method, the first equation is solved for d_1, with the answer substituted into subsequent equations. Each successive equation is solved similarly. The advantage of a direct method is that the program is guaranteed to converge on a solution after a finite number of steps. FEA programs that use wavefront, or frontal, algorithms do direct equation solving.
- Iterative methods requiring an indefinite number of steps to converge. The Gauss-Seidel solver, where initial estimates of the unknowns are made, is an example of iteration. An advantage of iterative methods is that they may converge on an answer quickly. On the other hand, they may never converge.

These solvers are most often used in 3D analysis with solid elements, in nonlinear design, or where similar analyses have provided a good set of starting approximations.

Find the answer. The motivation for doing a finite-element analysis is to determine the physical changes in a design resulting from applications of outside forces. Once element nodal variables such as displacements, temperatures, or potentials are determined, stress, heat flux, or field strength can be calculated.

Display and interpret results. Graphic presentation, with stress, heat flux, or field strength mapped in color contours or shaded plots, is common today. All systems still print nongraphic reports, but these are difficult to interpret.

---

modeling methods each have specific limitations, some advanced programs combine primitive and boundary-definition techniques in unified packages.

Early solid modelers worked in batch mode, which limited their use as interactive modelers. Although these solid modelers could be sped up by allowing them to approximate edges and surfaces, the inaccurate models they produced made them inadequate for engineering design and manufacturing.

Today's solid modelers attempt to provide interactive operation while maintaining accuracy. The goal is to produce interactive solid-modeling systems that work faster than even wireframe techniques.

Graphics hardware made especially for solid modeling has recently become available to help reach this goal. For example, some workstations allow each stage of the graphics "pipeline" to operate independently for faster operation. In addition, special-purpose chips are used to speed up functions such as calculating the effect of light sources, shading, and removal of hidden surfaces.

FEA

Finite-element analysis (FEA) is a computer-based technique for solving field flow problems. The most common application is finding stresses and deflections in a structure. Essentially, the method divides a structure into small elements with easily defined stress and deflection characteristics. The finite-element method is based on arrays of large matrix equations that can only be realistically solved by computer. Most often, FEA is performed with commercial programs. In many cases, these programs require that the user only know how to properly prepare program input.

The first step in finite-element analysis is creation of a model that breaks a structure into simple standardized shapes or by a common coordinate grid system. The coordinate points, called nodes, are locations in the model where output data are provided.

More than one type of element can be used in a model, including 2D elements where all forces and displacements act in a plane. Axisymmetric elements for solids of revolution are also

COSMOS/M

FEA programs available from $1550

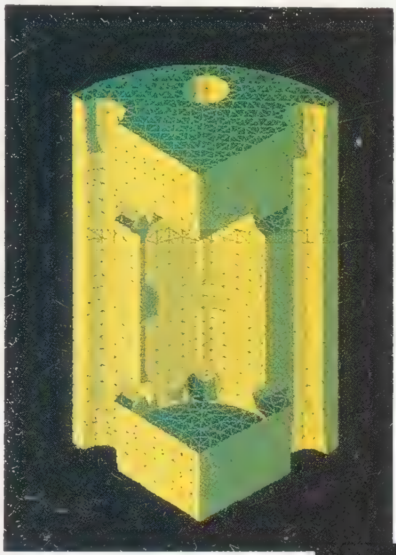
Automatic 3D Meshing ... it's easy!

COSMOS/M FEA is fast, reliable and affordable

shing is perhaps the most time nsuming pect of alyzing ur 3D dels - metimes, re than % of your e is dedicated to taining a sh that ovides curate sults.

me vings!

w ... with SMOS/M's w easy to use 3D omatic meshing capability ... u can realize significant time ings in just meshing alone. omatic 3D meshing makes the deling of complex structural, rmal, fluid and electromagnetic lysis a cinch.



3D solid mesh

w does it work?

easy! You define the geometry ed on either simply- or multiply- nnected 3D geometries. The tem is so flexible that you can del a wide variety of surfaces, ions and even solid entities with ities. Then, you can choose the ropriate mesh density and let the nputer do the rest!

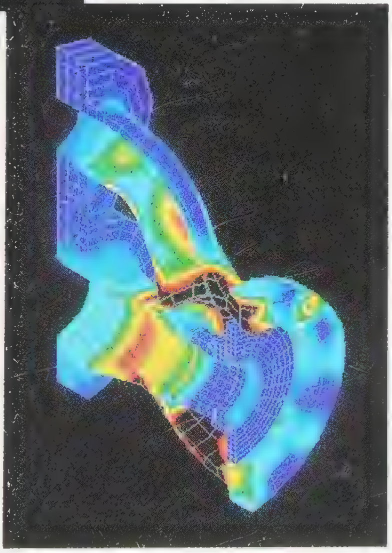
re accurate results, faster.

aspect ratio of each element is omatically checked, and oothed if necessary, to improve overall global aspect of the sh. Even models with drilled holes at arbitrary angels or complex intersections can be easily meshed with COSMOS/M. In addition, with the implementation of the P-method, COSMOS/M's automatic meshing can be used to solve complex solid models with a relatively coarse mesh to achieve the required accuracy.

It is really simple to use!

With 3D automatic meshing, you can significantly shorten your analysis time. Let COSMOS/M do the work for you. What can be simpler than that? Just imagine what you can do with all the extra time on your hands. Less wait. More reliable results.

Stress contour plot



The combination of COSMOS/M and your PC or workstation makes FEA fast, easy, reliable ... and affordable.

ANALYSIS:

- ☐ STATICS
  Linear/Nonlinear
- ☐ DYNAMICS
  Linear/Nonlinear
- ☐ HEAT TRANSFER
  Linear/Nonlinear
- ☐ FLUID FLOW
  Laminar, Turbulent
- ☐ ELECTROMAGNETICS
- ☐ FATIGUE
- ☐ CRASH DYNAMICS
- ☐ BUCKLING
- ☐ DESIGN OPTIMIZATION
- ☐ SHELL & SOLID OF REVOLUTION

FEATURES:

- ☐ H- & P-Method adaptive meshing
- ☐ Substructuring
- ☐ Composite/Sandwich
- ☐ Plasticity, Large Strain, Creep, etc.
- ☐ ANSYS®, NASTRAN®, PATRAN®, SINDA, Pro/ENGINEER®, AutoCAD®, other CAD Interfaces

RUN YOUR OWN DESIGN PROBLEMS ... CALL NOW FOR A FREE 50 NODE VERSION OF COSMOS/M

(310) 452-2158

ANSYS® is the registered trademark of Swanson Analysis Systems,Inc. AutoCAD® is the registered trademark of Autodesk, Inc. NASTRAN® is the registered trademark of NASA. PATRAN is the registered trademark of PDA Engineering. Pro/ENGINEER® is the registered trademark of Parametric Technology Corporation

1661 Lincoln Blvd.,
Suite 200,
Santa Monica,
CA, USA 90404
tel. (310) 452-2158
fax. (310) 399-6421
telex. 705578

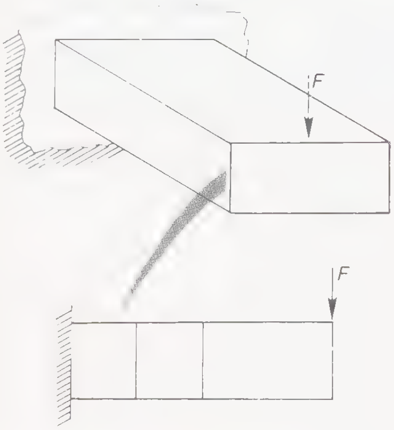
STRUCTURAL RESEARCH
& ANALYSIS CORPORATION

Circle 549

2D but have node displacements in radial and axial directions. Three-dimensional solid elements are used where forces and displacements act in all three directions or when a structure has a complex geometry that does not allow 2D analysis. Finally, specialty elements such as shells, plate, and beam types are used where sections of a structure behave according to conventional shell, plate, and beam theory.

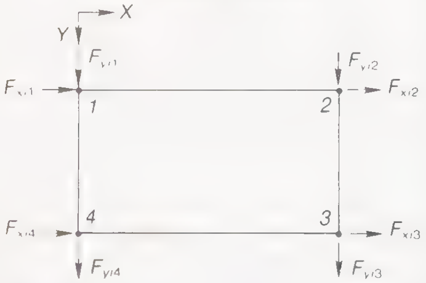
Elements with nodes at vertices generally model only a linear variation of displacement with constant strain. Elements are also available, however, with nodes between the vertices. These elements can model high-order variations in displacement and strain within an element. Elements with nodes along their sides are isoparametric. Additional nodes allow element sides to

BASIC FEA



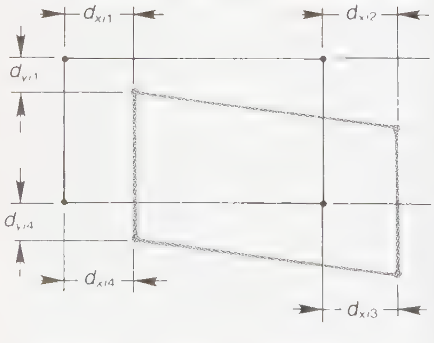
Beam is geometrically divided into elements to produce finite-element model.

NODAL FORCES



Each element of this two-dimensional model has four nodes, each with two nodal forces and two degrees of freedom.

NODAL DISPLACEMENTS



A finite-element model can be thought of as a system of solid springs. When a load is applied to the structure, all of the elements deform until all forces balance. For each element in the model, equations can be written relating displacements and forces at the nodes.

The element shown here, for example, is a 2D quadrilateral having four nodes. Each node has two degrees of freedom associated with it (displacements in X and Y directions), so that the element has a total of eight degrees of freedom. There must also be a nodal force for each nodal degree, so there are also eight nodal forces for the element.

These displacements and forces are identified by a coordinate numbering system for entry into the computer program. For example, d_{xi1} is the deflection in the X direction for element i at node 1, while d_{yi1} is the deflection in the Y direction for the same node in the same element. Forces are identified in a similar manner, so that F_{xi1} is the force in the X direction for element i at node 1.

An equation relating displacements and forces for the element takes the form of basic spring equation, $F = kd$. For four nodes

$$\begin{array}{l}
k_{11}d_{xi1} + k_{12}d_{yi1} + k_{13}d_{xi2} + k_{14}d_{yi2} + \ldots + k_{18}d_{yi4} = F_{xi1} \\
k_{21}d_{xi1} + k_{22}d_{yi1} + k_{23}d_{xi2} + k_{24}d_{yi2} + \ldots + k_{28}d_{yi4} = F_{yi1} \\
k_{31}d_{xi1} + k_{32}d_{yi1} + k_{33}d_{xi2} + k_{34}d_{yi2} + \ldots + k_{38}d_{yi4} = F_{xi2} \\
k_{81}d_{xi1} + k_{82}d_{yi1} + k_{83}d_{xi2} + k_{84}d_{yi2} + \ldots + k_{88}d_{yi4} = F_{yi4} \\
\vdots \qquad \vdots \qquad \vdots \qquad \vdots \qquad \vdots \qquad \vdots
\end{array}$$

The k factors are stiffness coefficients relating the nodal deflections and forces, and are calculated by the finite-element program from material properties such as Young's modulus and Poisson's ratio, and from the element geometry. Thus, in the example, coefficient k_{13} relates deflection 3 and force 1.

The set of equations can be written in matrix form

$$\begin{bmatrix}
k_{11}k_{12}k_{13}\cdots\cdots k_{18} \\
k_{21}k_{22}k_{23}\cdots\cdots k_{28} \\
k_{31}k_{32}\cdots\cdots k_{38} \\
k_{41}k_{42}\cdots\cdots k_{48} \\
k_{51}k_{52}\cdots\cdots k_{58} \\
k_{61}\cdots\cdots k_{68} \\
k_{71}\cdots\cdots k_{78} \\
k_{81}\cdots\cdots k_{88}
\end{bmatrix}
\times
\begin{bmatrix} d_{xi1} \\ d_{yi1} \\ d_{xi2} \\ d_{yi2} \\ d_{xi3} \\ d_{yi3} \\ d_{xi4} \\ d_{yi4} \end{bmatrix}
=
\begin{bmatrix} F_{xi1} \\ F_{yi1} \\ F_{xi2} \\ F_{yi2} \\ F_{xi3} \\ F_{yi3} \\ F_{xi4} \\ F_{yi4} \end{bmatrix}$$

If degrees of freedom and nodal forces are consecutively numbered ($d_{xi1} = d_1$, $d_{yi1} = d_2$, $F_{xi1} = F_1$, $F_{yi1} = F_2$, and so forth), the matrix can be renumbered to show how stiffness coefficients relate nodal forces and deflections.

When a structure is modeled, individual sets of matrix equations are automatically generated for each element. The elements in the model share common nodes so individual sets of matrix equations can be combined into a global set of matrix equations. This global set relates all the nodal degrees of freedom to the nodal forces, and the nodal degrees of freedom are solved simultaneously from the global matrix. When the displacements of all the nodes are known, the state of deformation of each element is known. And, if deformation of each element is know, the state of stress and strain within the element are also known.

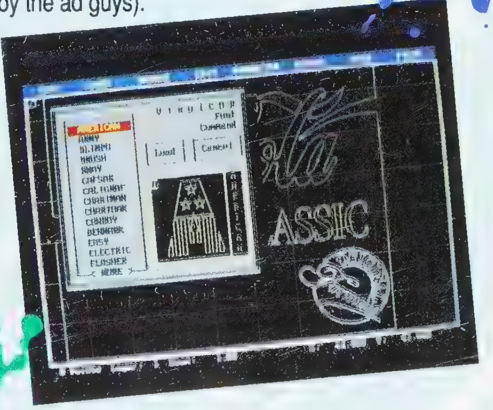
The finite-element method is, for simple static analysis, a two-step process. The nodal displacements are first simultaneously calculated from the element stiffness and the nodal forces, both internal and external. Next, the stresses are calculated, generally at the centroid of each element. Because the displacements are calculated for only a finite number of points in the structure, the finite-element method is a numerical approximation rather than an exact solution.

"Aw...what the heck!"

CALL IT VINYLCAD AND SELL IT CHEAP!

American Small Business Computers, Inc. (ASBC) introduces VinylCAD. It sells for $799.95. It is a complete PC computer software system for making vinyl signs. It will run on your PC with virtually any vinylcutter. It's the software you've heard rumors about for months! ◆ But...It almost wasn't called VinylCAD and it almost sold for a great deal more money. Here's the story: VinylCAD was developed by ASBC in response to requests by DesignCAD users. DesignCAD, ASBC's primary product, is a world renowned 2D and 3D CAD program. There are currently more than 250,000 DesignCAD users worldwide. Many are using DesignCAD for vinyl cutting. VinylCAD is the culmination of more than a year's development in conjunction with many vinyl cutting industry experts. ◆ The marketing people hated the name "VinylCAD". They said it didn't have any *life*, no *feeling*. It just didn't *sing*! They also said the price ($799.95) was too low for quality software. They noted many competing products sold for *thousands* of dollars. They said people wouldn't believe quality software with this number of *unbelievable features* could sell at such a low price. ASBC consulted marketing experts and industry experts. We asked accountants their opinion. Finally in the Great American Tradition the boss said, "Call it VinylCAD and sell it *cheap*! Let's see the other guys beat this price!" ◆ Because of the storytelling above, we don't have room to list all of the VinylCAD features (The advertising guys hated this ad–too much trivial copy they said!). So, here is a really short list of VinylCAD features. For the complete list call the number below, and we will send a great 8-page brochure (done by the ad guys).

ONLY $799.95



- ◆ Great user interface–drop-down menus and pop-up screens!
- ◆ 50 different typefaces–with our text distortion you get an almost unlimited number of fonts!
- ◆ Fantastic text distortions–easy, fast, and powerful!
- ◆ Text-inline and text-outline–ditto above: easy, fast, and powerful!
- ◆ Scan conversion included–convert scanned logos, etc. to VinylCAD drawings!
- ◆ Great manuals–easy to read, easy to use!
- ◆ Text kerning second to none–kern text automatically or manually!
- ◆ Sign panelling–no limit to sign size!
- ◆ Zooming, dragging, layering, rotating, bending and so forth and so on–There are *lots* of other commands and features!

FOR FURTHER INFO CONTACT:

AMERICAN SMALL BUSINESS COMPUTERS, INC.
327 SOUTH MILL STREET
PRYOR, OKLAHOMA 74361
PHONE (918) 825-4844
FAX (918) 825-6359

IN EUROPE CONTACT:
AMERICAN SMALL BUSINESS COMPUTERS, EUROPE
102 RUE LA FONTAINE
F75016 PARIS, FRANCE
PHONE 331 4520 2791
FAX 331 452 06539

Circle 550

form curved boundaries. Isoparametric models can cut model construction times, but require more processing time per element.

Nodal stiffness properties for each element are calculated by the finite-element program and arranged into matrices within the computer. These parameters are then processed with applied loads and boundary conditions for calculation of displacements, strain, natural frequencies, or other data specified by the program.

Generally, the finer the mesh, the more accurate the analysis. In many cases, finite-element models are developed for prototype designs for which experimental data can be obtained. Once finite-element analysis results and experimental data are correlated, design modifications are made, and these subsequent changes are often tested through finite-element analysis before being implemented on actual prototypes.

Finite-element results predict relative changes in deflection and stress better than they predict absolute deflections and stress. If models of two similar structures are compared by finite-element analysis, the results will predict the proportional difference between the two more accurately than they will predict the absolute stress in either one.

Accurate predictions of relative deflection are useful in design work where modification to a structure or machine is contemplated. A finite-element baseline analysis can be made for an existing structure for which stress or deflection data are known. A comparison is made between finite-element results and known experimental data to calibrate finite-element results and provide a baseline. Proposed design modifications then can be compared to the baseline model.

The finite-element method is applicable in several types of analyses. The

FEA MODELING TECHNIQUES

Postprocessors simplify and speed interpretation of analysis results by graphically displaying output data that would be virtually unintelligible in tabular form. Output display may be contour stress plots, or deformed geometry and animation capabilities may show how the structure behaves under static and dynamic loads.

In constructing the finite-element mesh, preprocessors ostensibly free the user of many routine, repetitive, or otherwise time-consuming tasks. Geometric modeling, automatic-mesh generation, mesh copying, and element-reflection capabilities allow creation of nodes and elements.

However, most finite-element analysts consider creation of the mesh as much of an art as a science. The accuracy of the mesh is completely dependent on the type of geometry used as the basis of construction. For example, solid models often include approximations that make the basic model inaccurate. If the inaccuracies or discrepancies in the basic model relate to geometric considerations important for stress analysis, the finite-element mesh is inaccurate.

The time it takes to create the mesh also depends on the type of geometry used to create it and the techniques used to simplify mesh generation.

One common way to reduce the number of elements is by taking advantage of symmetrical part geometries. Parts such as automobile hoods may have two-sided symmetry. And rotating equipment, such as fans and flywheels, with a number of identical sectors have even greater symmetry. Most preprocessors have data-generation algorithms for copying these repeated patterns.

The number of elements may also be reduced through iterative modeling in which coarse models with few elements are manually refined with fine meshes in critical high-stress areas until the required accuracy is reached. In this way, expensive computer time is not used to overanalyze the entire structure. This type of modeling depends on the ease and speed with which the analyst can construct models and interpret output data.

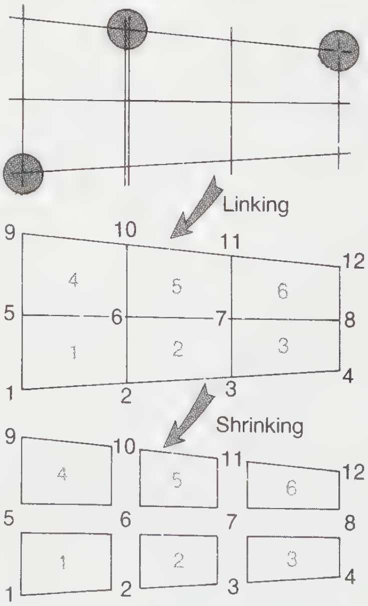
Global mesh-generation techniques are being developed that allow automatic creation and adaptation of a mesh on a solid component with little or no human intervention. Currently, these techniques produce a limited number of element types. Also, automatic, adaptive mesh generation based on results obtained from finite-element analysis needs to improve.

MODELING FOR PC FEA

Modeling describes designs in formats understood by FEA programs. Engineers can model a design using either text or graphics data.

- Text-file methods require engineers to type out lengthy node and element descriptions. Sometimes, the format used to describe a design differs within programs, depending on the solver chosen. A pure text-file method is impossible for occasional users to implement, so most PC FEA programs do not promote their use.
- Text-based model builders automate modeling somewhat. They prompt the engineer for information, and automatically format the file. Most PC programs include a text-based model builder.
- The easiest way to develop an FEA model is through a graphics program. Some PC programs include linkers that will accept CAD data from programs and prepare it for finite-element analysis. Other programs include modelers called preprocessors. Today, engineers must enter detailed geometry into these modelers. Newer preprocessors may allow engineers to prepare models by simply describing design parameters.

HOW A LINKER WORKS



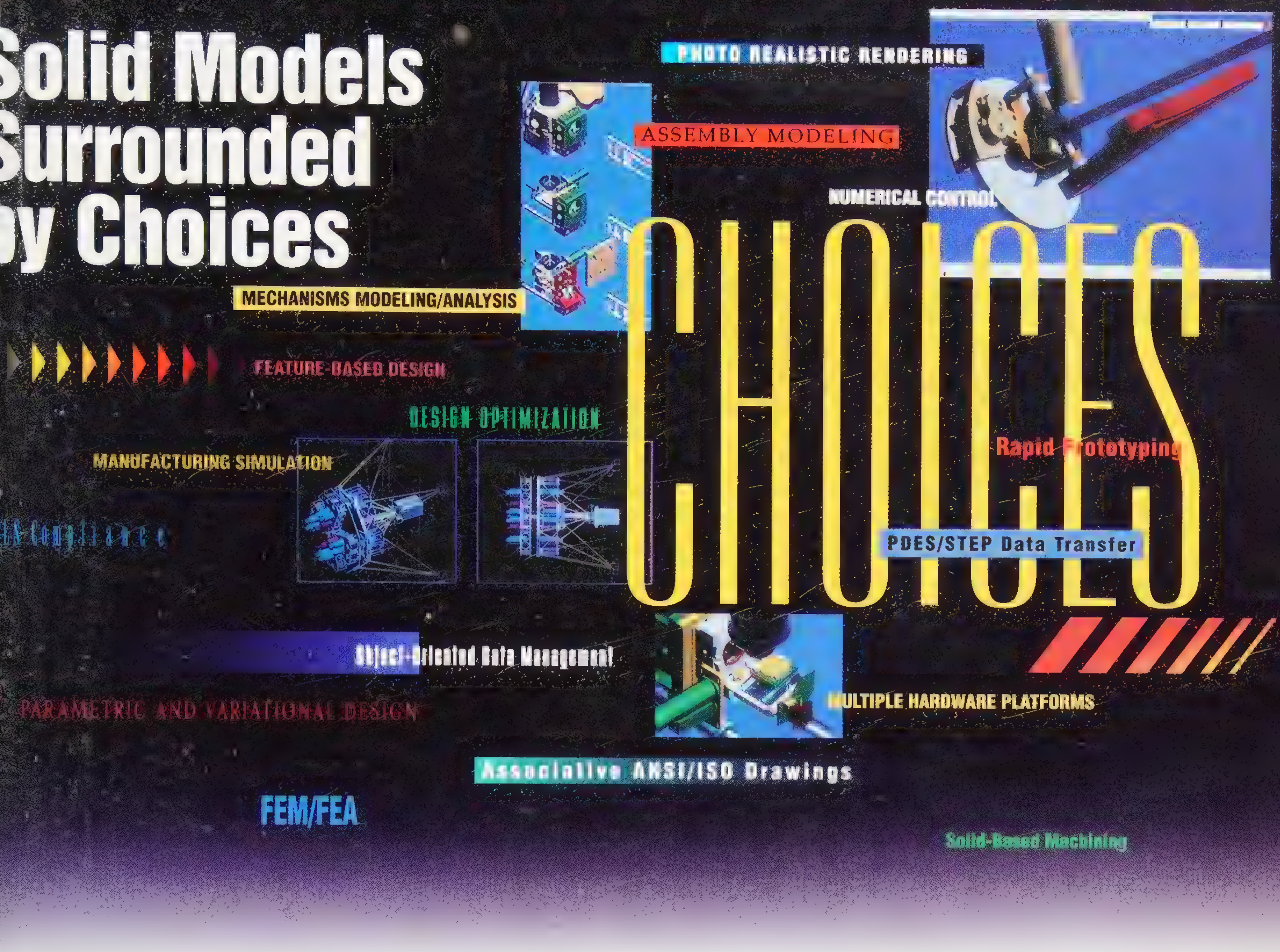
Detects and eliminates duplicate lines if they exist. Fills in lines that almost intersect.

Trims lines that overlap. Turns the lines into nodes and elements. Some linkers number nodes automatically, while others require engineers to do the numbering.

By using the shrink command, the engineer verifies that no elements are lost.

RIES TECHNOLOGY CONCEPTSTATION

Solid Models Surrounded by Choices



Freedom of choice! That's what
ou get with ConceptSolids,™ the
vorld-class solid modeler in our
NIX-based ConceptStation® predic-
ve engineering software series.

ConceptSolids is based on ACIS®–
ne open modeling kernel that will
arry mechanical engineering into
ne 21st century.

ConceptSolids gives you unlimited
otential in the design phase and
eyond. Choose from Aries' comple-
nentary software modules providing
arametric modification, finite ele-
nent analysis (including thermal),
nechanisms analysis, material prop-
rty management, mass and section
roperties, an equation solver, and
NSI/ISO standard drawings. Many
f our customers have cut product
development time by 50 to 80 percent.

Also choose from the best products of many other companies adopting ACIS, including Autodesk, Hewlett Packard, CADAM, Schlumberger, and many others. ConceptSolids is automatically compatible with these ACIS-based products. Our **Open Choice**™ program identifies compatible products for you.

With ConceptSolids, you're not captive to a proprietary software scheme. You can choose "best-of-breed" solutions from many vendors to automate your entire development process.

Don't get trapped, get ConceptSolids — the **Open Choice** new generation solid modeler with built-in freedom of choice.

WIN A FREE SUN SPARCstation IPX!

Call 1-800-642-7437,
ext 333, or FAX your
business card to
1-508-458-2541
or complete the
ad-response card to
receive an IPX giveaway
registration form and
Aries product information.

ARIES
TECHNOLOGY

s Technology, the Aries logo, ConceptStation, ConceptSolids, and Open Choice are trademarks or registered trademarks of Aries Technology, Inc. ACIS is a registered trademark of Spatial Technology
Sun and IPX are registered trademarks of Sun Microsystems, Inc. SPARCstation is a registered trademark of SPARC International, licensed exclusively to Sun Microsystems, Inc
to credits: Electron microscope courtesy of Leica Cambridge Limited, U.K., Spacecraft fluid interface system courtesy of Moog Space Products, East Aurora, N.Y

OFTWARE FOR PREDICTIVE ENGINEERING

Circle 551

most common is static analysis, which solves for deflections, strains, and stresses in a structure under a constant set of applied loads. Material is generally assumed to be linear elastic in FEA, but nonlinear behavior such as plastic deformation, creep, and large deflections also can be analyzed.

Natural-frequency analysis calculates the free-vibration natural frequencies and associated mode shapes of a structure. This analysis predicts critical operating conditions for machinery and is used in conjunction with experimental signature analysis.

Transient-dynamic analysis determines the time-response history of a structure subjected to a forced displacement function. The structure may behave linearly, or in some cases, friction plasticity, large deflections, or gaps may produce nonlinear behavior. Once the time response history is known, complete deflection and stress information can be obtained for specific times. A similar method is forced-harmonic response analysis, which calculates the steady-state response of a structure to a continuous set of sinusoidal loadings. Complex displacements and phase angles are calculated. Deflections and stresses may again be calculated at specific times.

Heat-transfer analysis can solve steady-state and transient heat-transfer problems. In most cases, thermal-output data are applied as input to a structural-analysis problem to determine thermal deflections and stresses.

Mechanism analysis

Kinematics analyzes motion in a defined mechanism. Synthesis, on the other hand, comes up with the best definition of the mechanism through iteration. In synthesis, the designer describes the parameters of the mechanism and the program develops alternatives.

Synthesis is a more difficult problem

LINKING SCHEMATICS AND LAYOUT

Links between schematic capture and printed-circuit-board routing packages encompass three general areas: netlist formatting, physical file transfer, and back annotation.

First, information from the schematic must be converted into a netlist format compatible with the PCB routing software. Though there are a number of different netlist formats, most can be categorized as either part oriented or net oriented. Part-oriented netlists each part followed by the names of signals connected to the pins.

On the other hand, other programs use net-oriented netlists, where parts are itemized in terms of the circuit net to which they connect. Usually these packages also contain a separate component list.

Different netlist formats also handle chip packaging in dissimilar ways. Some routing packages can only recognize gates, while others recognize IC packages as well as gates. To use a PCB program that works with only chip packages, the schematic capture station must be able to assign each gate to a specific package.

Part names of the schematic capture workstation library must also relate to the corresponding entities in the PCB software. In general, the two types of programs have two different names for the same part. For example, a PCB system that only recognizes package types might denote a specific part as "Dip8," where the schematic capture software refers to the same component as "74F74."

Netlist-generation software must translate names to allow for such mismatches. Other information that must be specified along with component names includes the existence of circuit areas that have critical layout requirements. The circuit designer specifies such data during the definition of the schematic. Typical information specified includes maximum allowable trace lengths, package placements, and the possible use of multiple ground planes for different groups of packages.

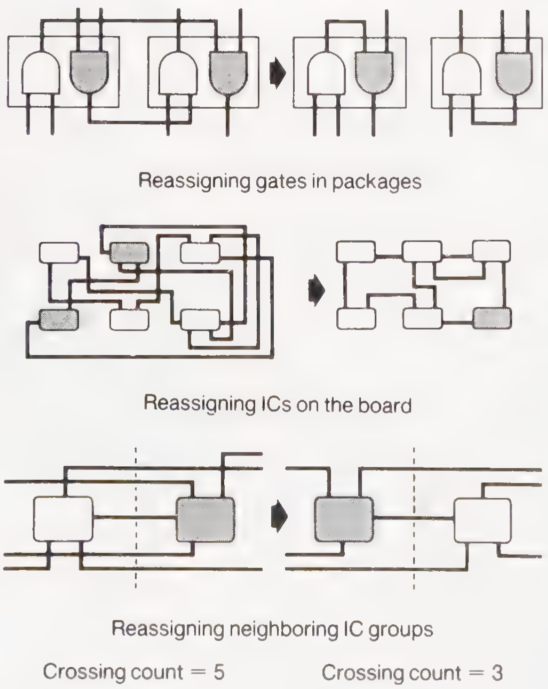
Most netlist formats do not contain mechanisms for specifying all this information. A great deal of such data is handled on an *ad hoc* basis by PCB and circuit designers.

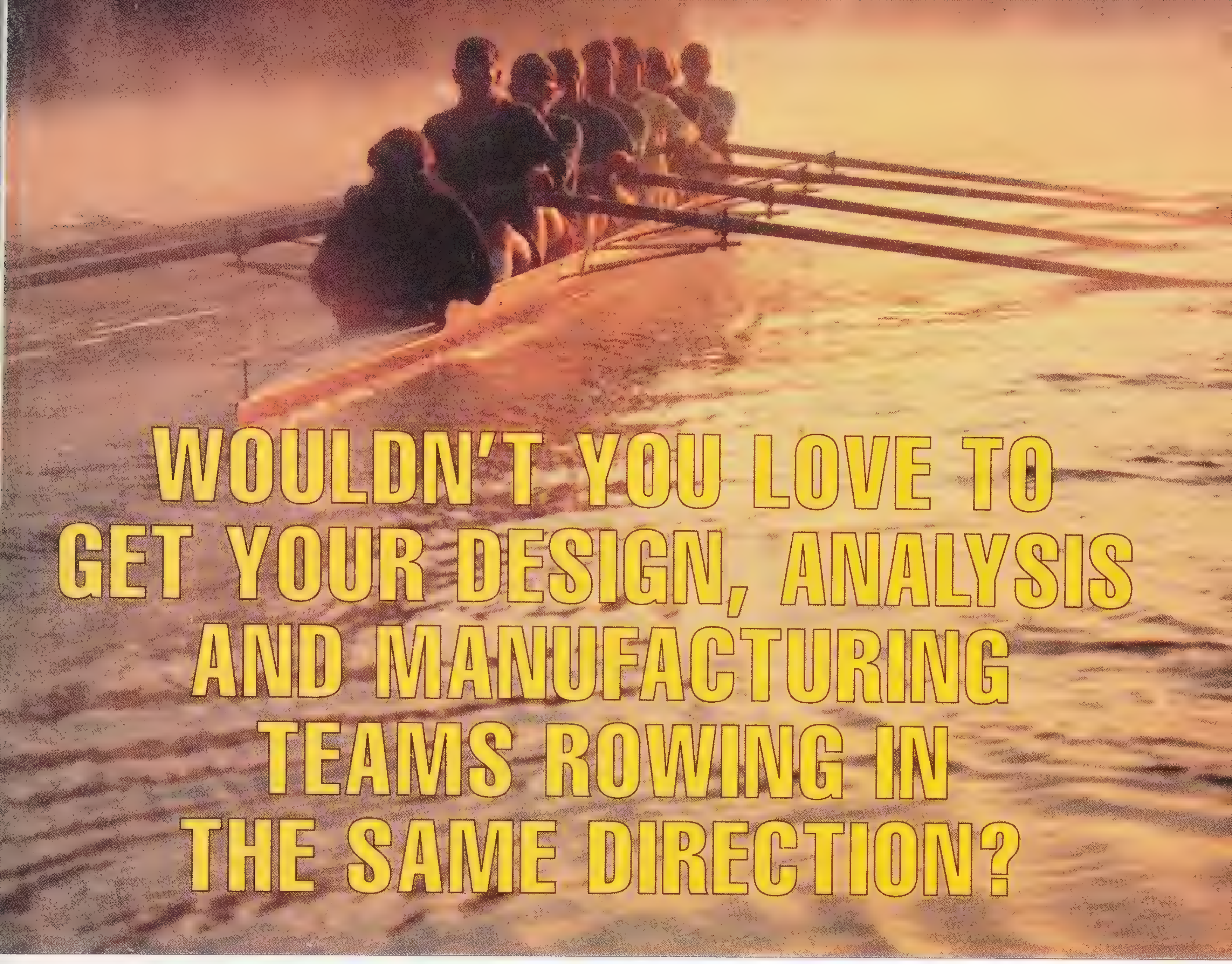
During the layout of the PCB, board designers may alter the grouping of gates within the IC packages, making changes in the plan of the schematic to obtain a better board layout. These changes typically involve reassigning equivalent pins on gates and similar operations. At the completion of the board layout, these changes are fed back to be reflected on the schematic in a process called back annotation.

The most common types of changes involve swapping gates and pins within IC packages to make the PCB easier to route. It may be difficult to back annotate these kinds of changes between some PCB and schematic programs. And some kinds of changes made during PCB routing cannot be back annotated. These changes include deleting or adding components.

Back annotation is important because it reveals major differences between PCB and schematic capture programs. Some systems such as Scicards or HP PCDS keep track of changes that have been made and return a change file. This makes back annotation easy. Other programs simply generate a netlist incorporating the changes. If the netlist of the finished circuit is to provide sufficient information about changes, each component must have a unique identifier which the board software system does not change.

AUTOPLACE ROUTINES


Reassigning gates in packages
Reassigning ICs on the board
Reassigning neighboring IC groups
Crossing count = 5
Crossing count = 3



Data file incompatibility often frustrates companies who want to link CAD, CAM and analysis tools. With Cadkey, the problem no longer exists.

Cadkey solutions make the full integration of design, analysis and machining not only possible, but easy to learn, easy to use, and affordable.

CADKEY®, ANALYSIS® and CUTTING EDGE® are part of an award-winning family of concurrent engineering desktop tools for manufacturing. All share an open architecture system which allows a free flowing exchange of information between databases and functions. 100% file compatibility ensures seamless — and simultaneous — design, analysis, and tool path data generation and transfer.

Cadkey helps companies reduce design-to-manufacture cycles while improving quality and profitability. And it's all backed by exceptional technical support, product upgrades, training/consulting services and an international network of dealers and distributors.

Find out how to get all your company's oars in the water at the same time. Call Cadkey today and request your free copy of our "Rowing in the Same Direction" poster.

Cadkey, Inc.

4 Griffin Road North, Windsor, CT 06095
(203) 298-8888 • FAX: 298-6401• 800-654-3413

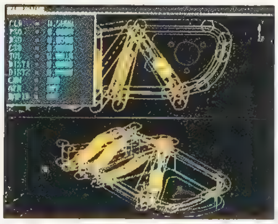
© CADKEY, ANALYSIS and CUTTING EDGE are registered trademarks of Cadkey, Inc.

Circle 552

YOU'RE LOOKING AT A $5,500 ERROR THAT COULD HAVE EASILY BEEN AVOIDED.

CAD/CAM data incompatibility and transfer errors are big problems for automated machine shops. A recent NTMA* study found that *51%* of companies surveyed experienced data translation difficulties, and *25% had to completely re-create data.* Every "miss" costs between $4,000 and $5,500 in scrap, rework and delivery delays, not to mention a reduction in competitive position and lower profits.

Why take chances? With CADKEY® and Cutting Edge® you'll have 100% failure-free CAD to CAM data transfer. You can also transfer files from another CAD with IGES, DXF and CADL® utilities included with Cutting Edge.

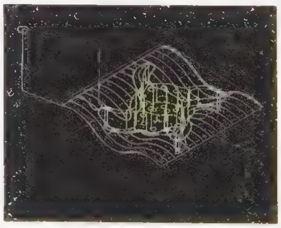


Cutting Edge features simultaneously active viewpoints (tool path shown here).

Cutting Edge can also be used as a stand alone CAM system for 3-axis milling, drilling, boring, reaming, slotting, pocketing, tapping and contouring. Tool path prove out — the immediate and complete verification of the tool path before cutting — reduces material waste. A choice of 100 post processors assures maximum flexibility.

Cadkey's family of desktop concurrent engineering tools now make the seamless integration of *all* design, analysis and manufacturing functions not only possible, but affordable.

CADKEY is easy to learn and use. A common data base makes it possible to integrate reverse engineering, inspection, rendering, solids and surface modeling tasks into any design and manufacturing operation.



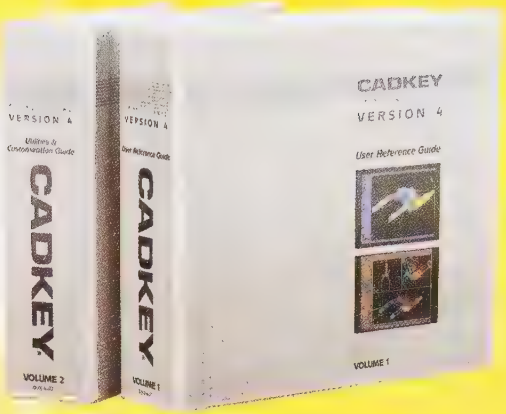
3-axis machining with 100% data transfer reliability.

Get the most flexible and versatile CAD/CAM system you can buy. Call your nearest Cadkey dealer or contact Cadkey today.

CUTTING EDGE

Cadkey, Inc.
4 Griffin Road North, Windsor, CT 06095
(203) 298-8888 • FAX: 298-6401 • 800-654-3413

CADKEY, Cutting Edge, CADL are registered trademarks of Cadkey, Inc. *A 1991 study done by the Detroit Chapter of the National Tooling and Machining Association found that dataset errors cost tool and die shops an average of 8% in excess costs per tooling job; $4,000 to $5,500 lost PER JOB in scrap and rework and a 23% to 27% increase in lead times



SUN SHINE

The Sun SPARCstation™ 2, one of the best selling workstations in history, is a pretty impressive machine. Completely compatible with existing equipment, it combines PC versatility, UNIX® multitasking capabilities and mainframe power into a highly efficient, flexible, low-cost computing solution. And, it promotes concurrent engineering by allowing workgroups to share files.

CADKEY® software — equally impressive — is leading the way in 3-D mechanical design/drafting and integrated manufacturing solutions, and now it runs on SPARCstation 2.

CADKEY's success has come from focusing on mechanical engineering productivity, not trying to become "all things to all people." The result is the most comprehensive and useful mechanical design and drafting software you can buy. And with over 75,000 installations, CADKEY is actually preferred by engineers because it works like an engineer: clear, logical, flexible, precise.

Features that have helped CADKEY earn an award-winning reputation include an intuitive user interface, live tutorials, online help, machine precision accuracy, plus integrated solutions for surfaces and solids modeling, rendering, machining and analysis. All supported by an international sales and service network.

CADKEY software and the Sun SPARCstation 2 system offer engineers the optimum in speed, processing power, flexibility and ease of use...at a very affordable price. The benefit to you? More work can now get done faster and at lower costs.

So if you think the Sun SPARCstation 2 is hot, wait until you fire it up with CADKEY programs. With a combination like this, it's going to be pretty hard NOT to outshine — and outdistance — the competition.

Find out how to put the Sun SPARCstation 2 and CADKEY to work for you, contact your authorized CADKEY dealer or Sun Microsystems reseller. Or call CADKEY directly at 1-800-654-3413.

sun
microsystems

Cadkey, Inc.
4 Griffin Road North, Windsor, CT 06095
(203) 298-8888 • FAX: (203) 298-6401

Sun Microsystems and the Sun logo are registered trademarks of Sun Microsystems, Inc. SPARCstation is a trademark of SPARC International, Inc., licensed exclusively to Sun Microsystems, Inc. Products bearing the SPARC trademark are based on an architecture developed by Sun Microsystems, Inc. UNIX is a registered trademark of UNIX System Laboratories, Inc. CADKEY is a registered trademark of Cadkey, Inc. U.S.A. ©1991, Cadkey, Inc.

WE'VE LOWERED THE COST OF HIGH PERFORMANCE FOR CADKEY.

NOW THE PERSONAL DECSTATION STARTS AT $3995.

Today's applications like CADKEY® demand the balanced performance of a complete workstation and only the UNIX®-based Personal DECstation™ gives it to you at such an affordable price.

Many of the features other low-priced workstations offer, such as an open bus, 8-plane graphics and color, are add-ons. With the Personal DECstation, they're standard. And it's built for the future with new CPU and graphics cards, network interconnects and upgrades, multimedia technology and full Advanced Computing Environment (ACE) compatibility.

The Personal DECstation from Digital. The power of a workstation. The productivity of a workstation. The price of a PC.

CADKEY AND DIGITAL: EASY AND AFFORDABLE 3-D MODELING

There has never been a more productive and cost-effective mechanical engineering environment than the award-winning CADKEY on Digital's Personal DECstation. CADKEY uses logic and flexibility to make your 3-D modeling and 2-D drafting easier. The on-line tutorial and context-sensitive help menu functions walk you through the system, and skilled technicians are just a phone call away. CADKEY on the Personal DECstation gives you powerful mechanical drafting on a UNIX workstation at a price you can afford. To find a CADKEY reseller near you, please call 1-800-654-3413.

ADVANCED COMPUTING ENVIRONMENT

digital™

© Digital Equipment Corporation 1992. The DIGITAL logo and DECstation are trademarks of Digital Equipment Corporation. UNIX is a registered trademark of UNIX System Laboratories, Inc., in the USA and other countries. CADKEY is a registered trademark of Cadkey, Inc.

DIGITAL. THE OPEN ADVANTAGE.

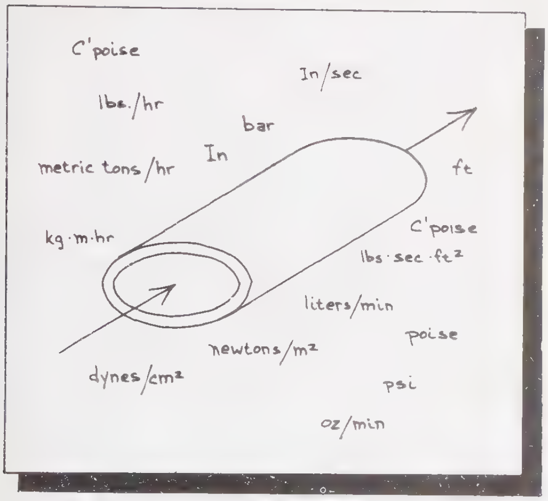
New FLUIDTOOLS with Elbows and Valves solves pipe and tube flow problems on your PC

Wouldn't it be nice if you could solve flow problems without having to look up all of your data? With FLUIDTOOLS, you can do just that! It's easy as A-B-C.

- Just enter your data in whatever units you wish...
- Request FLUIDTOOLS to return answers in the units you want...
- Press "Calculate"...

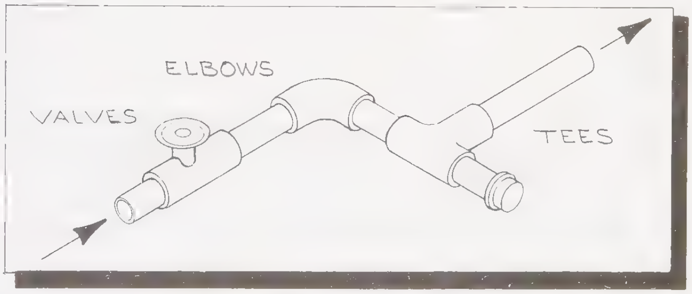
It's that simple!

Program accepts mixed units



Developed by Neat Solutions

FLUIDTOOLS solves parameters for liquid and gas flow problems such as diameter, length, flow rate, pressure, Reynold's numbers, specific gravity of gases at temperature and pressure, viscosity, and flow velocity.



Some of the important features of FLUIDTOOLS--

Automatic unit conversion... enter data in mixed units and FLUIDTOOLS automatically calculates in the units you want • Friction factors are automatically calculated from internal empirically developed equations. But these factors can be easily overridden • Program data base includes elbows, valves and fittings, viscosity and specific gravity tables, and pipe sizes • A wide range of common and uncommon metric and English conversion factors are included and are easily expandable to accept user-defined data • Preset friction factors for tube, smooth or rough pipe... or program accepts user-defined factors • Program can save all user-defined data. All tables can be edited and expanded using the special text editor included, or use your own word processor.

FLUIDTOOLS program disk and user manual **$295**

SYSTEM REQUIREMENTS:
IBM PC line of computers or 100% compatibles
MS/PC DOS 2.0 or higher
256K minimum memory

SATISFACTION GUARANTEED! Run FLUIDTOOLS on your PC. If the program doesn't perform as described, just return it within 30 days for full credit or refund!

Chargecard users order toll-free 800-321-7003
(in Ohio, call 216/696-7000) or send your order to:

Penton Education Division
1100 Superior Avenue
Cleveland, Ohio 44114

than kinematics. Unlike kinematics analysis, which starts with a mechanism design, synthesis starts with the basic description of a mechanism — number of links, number of joints and joint types, connectivity of links and joints, and specification of which links are grounded. Basic linkage types are defined within programs as kinematic chains. Component dimensions are not specified. The synthesis program then determines mechanism structures required to perform specific tasks. Synthesis also analyzes how well certain mechanism structures will satisfy design objectives.

Kinematic synthesis programs are used principally to design four-bar linkages, although some also synthesize six-bar linkages. The four bar, however, is one of the most versatile types of mechanisms for providing complex motion. Most synthesis software solves only certain classes of problems. First, the required mechanism must be classified as being either planar or spatial. Most mechanisms are planar, but contrary to popular belief, a planar mechanism does not necessarily lie in a single plane. Instead, its moving components — such as a parallel set of hinges — trace curves that lie in parallel planes. Spatial mechanisms have points whose paths are 3D and do not lie in parallel planes.

Some kinematic synthesis programs use graphics to make the software easier to use. Typically, the user specifies points and motion vectors with interactive graphics, which can be easily moved about the screen. After a number of points have been specified, the program will display possible locations of additional points to complete the mechanism.

After a mechanism has been synthesized, it may be animated on the screen to check for mechanical action. Viewing this animation allows users to judge criteria such as clearances of the moving links. Some systems permit these animations to be made with shaded images so the mechanism looks more realistic. For clarity, the display is usually color coded to differentiate links, fixed pivots, moving pivots, motion paths, and other elements.

Engineering mechanics

Kinematic analysis calculates large displacements, velocities, and acceleration of mechanisms without regard to the forces or mass properties acting on them. In kinematic analysis, the mechanism is driven by some outside force. Kinematic analysis assumes zero degrees of freedom, which means that each coordinate is constrained to a particular type of motion. Many times, mechanisms are constrained by tying their end points to ground.

Static-equilibrium analysis combines motion analysis with mass properties and force data to determine positions and joint-reaction forces of mechanisms at rest. Static analysis can also be done on mechanisms at various points in their range of movement, when zero velocity is assumed. Static models can have multiple degrees of freedom. Motion and force are uncoupled in this type of analysis. That is, the forces that act on the mechanisms are not a result of motion.

Dynamic analysis uses mass properties and forces to calculate positions, velocities, accelerations, and joint and constraint-reaction forces of all model parts when motion is coupled to forces in the system. Models may have any number of degrees of freedom. Dynamic analysis does not assume equilibrium in mechanisms. Analyses are done at discrete steps within a specified time interval. Each degree of freedom in a dynamics model is associated with an independent coordinate for which the analyst must specify both initial position and velocity.

Most dynamic-analysis programs are tailored to solving a certain class of problems. Many of the programs will solve kinematic problems as well, but software specifically designed for kinematic analysis is usually more efficient for this type of evaluation.

Large-displacement analyses are the most common type of dynamics problems. Large-displacement analyses are often nonlinear. They include many discontinuous effects, making mathematics extremely complicated. Software for handling these complex prob-

FEA FOR ELASTOMER DESIGN

Closed-form analytical solutions and handbook equations have been effective in reducing some of the cut-and-try iterations that are inherent to the design of simple elastomeric components. Techniques used in deriving these formulas, however, are of limited use in designing components with irregular geometries, shapes that are often found in real design problems.

Some assumptions used to obtain the more widely used equations are good approximations of physical reality, while others are overly idealistic. Most equations are based on the assumption that rubber stress-strain response is linear elastic, or that it is incompressible nonlinear elastic. The latter condition is often approximated by a simple hyperelastic-material model such as the two-constant, Mooney-Rivlin model. However, this model often does not reflect the full range of nonlinearity. Linear stress-strain behavior is an unrealistic assumption if the part suffers local straining beyond 10%, so nonlinearity applies in most cases.

In addition, most models overlook other important properties of elastomers. The effects of material hysteresis and time, for example, are neglected, which rules out the evaluation of time-dependent behaviors such as creep and relaxation. Closed-form solutions are also limited to components having the simplest undeformed and deformed (loaded) geometries. Deformed geometries are specified mathematically, based on an intelligent guess. This practice, frequently referred to as an "inverse method," uses the presumed geometry to obtain closed-form expressions for the resulting stress field and applied loads. In many cases, a "fudge factor" based on experience must be added to take care of any unexplained deviations between predictions and actual response.

Fortunately, more flexible and powerful alternatives to closed-form solutions are available for analyzing elastomeric parts. They are based upon approximate numerical techniques that subdivide the components body into small "cells" or elements. Both the finite-difference and finite-element methods use this approach.

Basic philosophy behind the finite-element method is piecewise approximation. Complicated problems are approximated by representing the solution for each element with a relatively simple relationship. These functions approximate distribution of actual displacements or actual stresses. Finite elements are interconnected at points on and within the body called nodes or nodal points. Accuracy of the solution increases with the number of elements used.

In addition to providing accuracy, FEA can be used to evaluate more design modifications than iterative building and testing, making it suitable as a design development tool. Major benefits include time savings and reduction in the number of prototypes needed to arrive at a final design.

GO FIGURE!

DesignCAD 2D. Like Leonardo da Vinci's concept of a rotary blade aircraft, it is ahead of its time, not only in technology, but also in cost and value.

DesignCAD 2D is only $349, and it has more and better features than the other CAD programs that cost $3,000!

And, if you're ready for a three dimensional CAD program, there is the state-of-the-art DesignCAD 3D . . . for only $499!

So, how come theirs costs several thousand dollars and ours costs a couple hundred? Go figure. (Why do you think the Mona Lisa is smiling like that?)

Computer Shopper Best of 1991
CAD/CAM Software

PC Magazine Editors' Choice
December 11, 1990
DesignCAD 3-D, Version 3.1

PC Magazine Editors' Choice
December 17, 1991
DesignCAD 2-D, Version 5.0

Buyers Assurance Seal

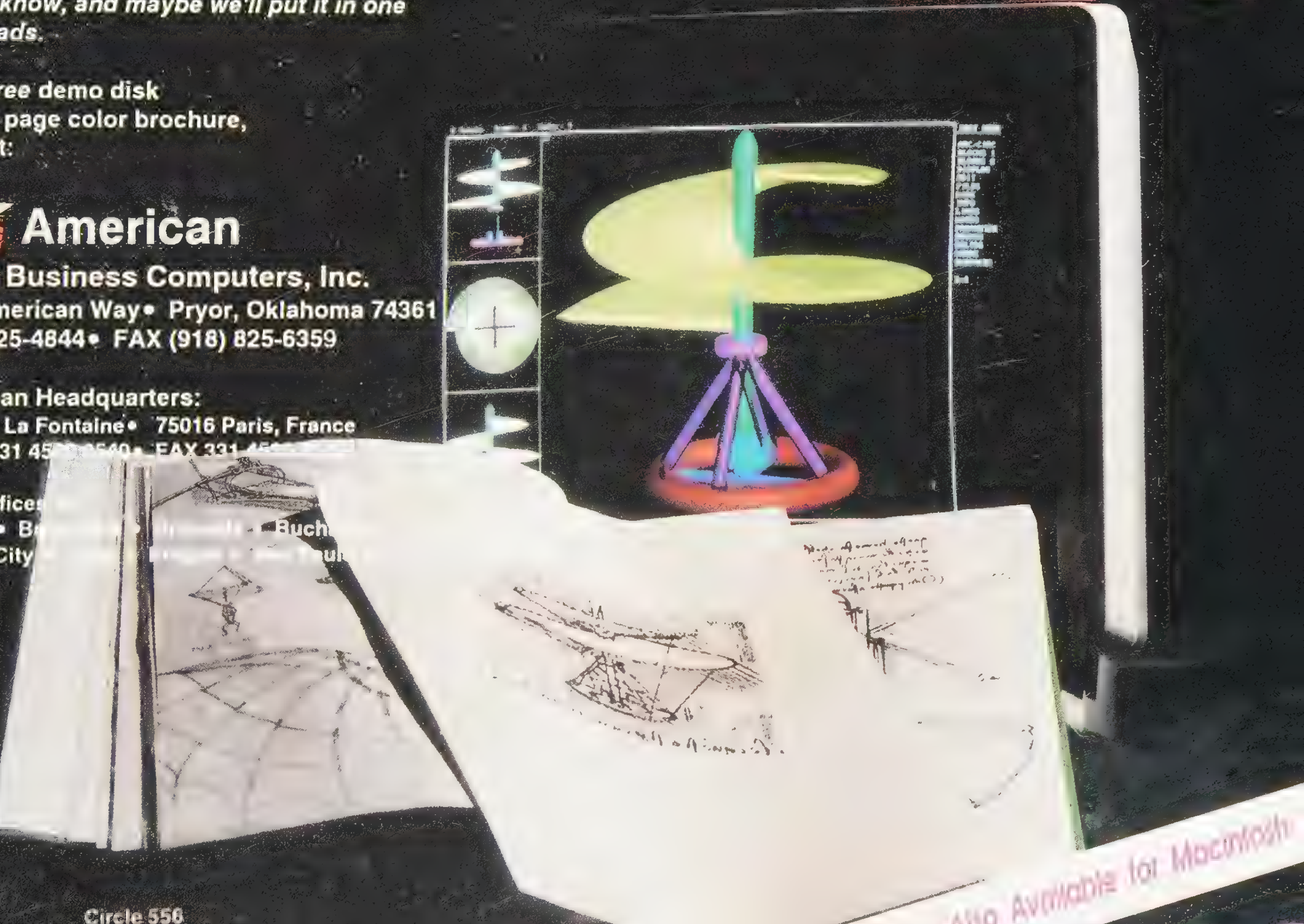
Your product designed with DesignCAD? Let us know, and maybe we'll put it in one of our ads.

For a *free* demo disk
and 16 page color brochure,
contact:

American
Small Business Computers, Inc.
One American Way• Pryor, Oklahoma 74361
(918) 825-4844• FAX (918) 825-6359

European Headquarters:
102 Rue La Fontaine• 75016 Paris, France
Phone 331 45 0540• FAX 331 45

Other offices
Athens • B Buch
Mexico City u



Also Available for Macintosh

Circle 556

lems often uses sparse-matrix methods and stiff-system numerical-integration algorithms.

The sparse-matrix approach solves for a large but sparse set of first-order differential equations. Numerous equations are used to describe the structure, but only a few finite terms occur in each equation. As a result, time and cost of processing these equations is much less than would ordinarily be involved.

Computer models for dynamic analysis include geometric data and mass properties of the structure as well as applied forces. The model often is created through part, joint, marker, force, and generator statements typed by the user at the terminal.

Part statements define geometry, mass, and moment of inertia of each rigid part of the structure. Joint statements describe contacts between moving parts that hold the assembly together. Joints can be specified as providing translational and rotational movement including those of revolute, spherical, screw, universal, cylindrical, and translational joints, as well as motion of a rack and pinion. Marker statements provide a point or coordinate system fixed on each part, orienting it to other parts and together defining the overall configuration of the system.

Internal-reaction forces in the system are selected from a library of standard force elements such as dampers and linear springs. In addition, user-written routines can be used to define other parameters.

Graphics pre and postprocessing tools for mechanical-analysis programs are not as well developed as they are in finite-element analysis. Part of the reason for the slower development is that mechanical-dynamics programs do not require detailed geometric input. All that is required are three points of geometry for each mechanism link, which are the two ends and center of gravity. Mass and inertia must also be defined for each center of gravity. However, despite the fact that the geometric models are simpler, it is still easier to visualize mechanisms and get geometry correct with graphics than by scribing the geometry with part statements.

Basic geometric data can be sent from CAD programs through direct interfaces. Interfaces from modelers and CAD programs to dynamics programs are not done through such standard interfaces as IGES because a critical component of a kinematics and dynamics model — the center of gravity — is not available through IGES except with specialized files that are difficult to use.

Because a complete geometric description is not required, mechanical analysis can be used early in the design cycle, before the final system shape is known. Engineers can design a system knowing only the mass and inertia characteristics.

However, complete geometric descriptions are required to properly postprocess a kinematics and dynamics model. Postprocessed models are used primarily as debugging tools to check for interferences. Realistic animation can be used to see motion that might be missed in a series of still pictures.

Dynamic-analysis output is also typically available in tabular form. Graphics may also be produced showing output quantities such as force versus time, or force versus displacement.

Most dynamic analysis can be done assuming rigidity, but in some cases, the ability to model flexibility can come in handy. Computational demands of flexible-body analysis are intense, how-

THERMAL ANALYSIS

Thermal analysis of electronic systems is performed to minimize heat buildup that shortens product life. Most often, such analysis is performed for printed-circuit boards (PCBs) to determine cooling requirements or so that components can be rearranged for cooler operation.

This thermal analysis can be done with finite-difference, network, or finite-element techniques. Finite-difference methods handle 2D linear-conduction problems quickly and economically. In fact, many such problems made to handle PCB design run on personal computers.

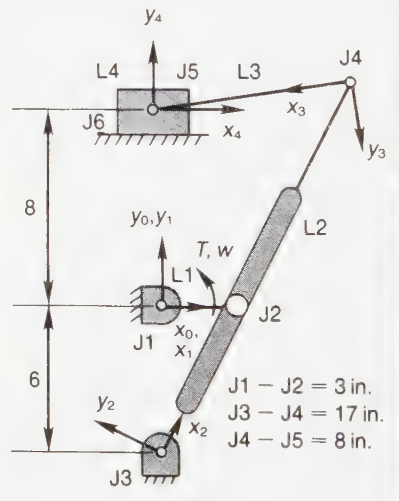
Network methods are similar to finite-difference technique, but are not restricted by model geometry. They can easily switch back and forth among 1, 2, and 3D thermal problems, and irregular geometries are easily modeled.

Finite-element analysis has only recently been adapted to evaluate thermal characteristics of electronic systems. FEA can handle irregular shapes and skewed meshes, but they may not be applicable to nonlinear thermal radiation problems.

DYNAMICS ON A PC

Several companies market 2D kinematics and dynamics software for PCs. These programs will do kinematic, force, dynamic, and static-equilibrium analysis of planar mechanisms composed of rigid links connected by revolute or slider joints. Complex systems can be analyzed by combining linkage models. These models can be subject to varying forces over different time intervals.

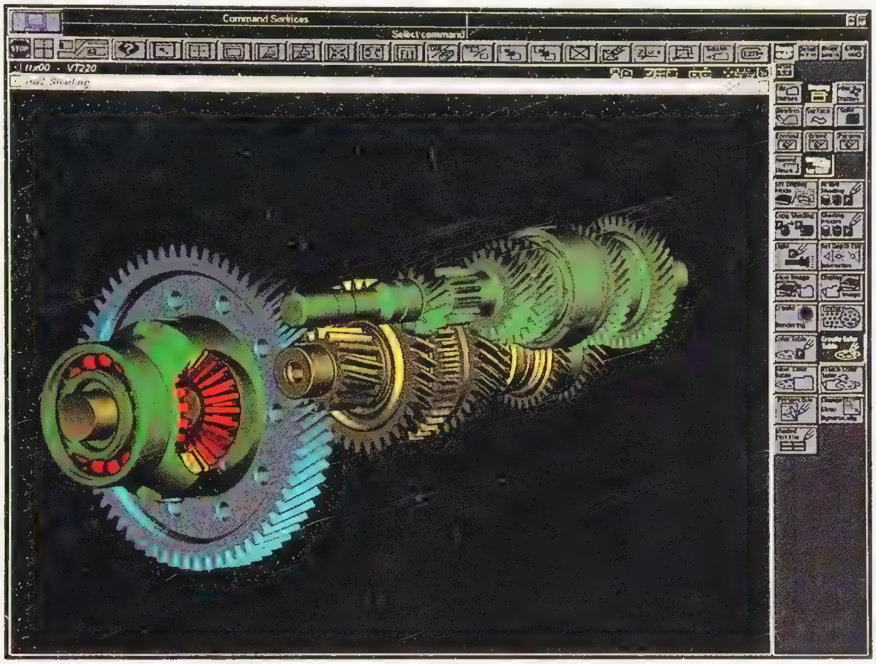
An example of a complex system is a quick-return mechanism composed of two kinematic loops, a slider joint, and a sliding pin joint. Dynamic-force analysis is required to determine the torque, T, required to drive the mechanism at a constant angular velocity of link L1. Joint-reaction forces at J2, J3, and J4 and acceleration of the slider also must be determined. L1 is assumed balanced and operating at a constant angular velocity; therefore, its mass properties are not required. However, mass properties must be defined for L2, L3, and L4. When the mechanism is analyzed, it is animated to illustrate general results. Reports are generated on the joint-reaction forces, driving torque and acceleration of the slider joint.



Mass properties (lbs)

Link	X	Y	Wt	I
L1	0.0	0.0	0.0	0.0
L2	8.5	0.0	5.0	0.5
L3	4.0	0.0	3.0	0.2
L4	0.0	0.0	10.0	0.0

I/EMS.
Easy, But Powerful.



The Modeling Solution From The People Who Understand Your Mechanical Design Problems.

If streamlining mechanical design is a problem, talk to us about I/EMS. Intergraph's Engineering Modeling System.

Our powerful tools work the way you do. When you use I/EMS, you'll get variational and parametric design features that free you to follow a natural workflow.

Move smoothly from wireframe to surface to solid geometry – and back. When you change the model, the drawing sheet automatically updates, and vice versa. You can consider more design alternatives because the models you create will be easier to change. You'll trim hours, even days, off your design time. And you'll develop a quality product – faster.

I/EMS power at your fingertips. Feature-based solids modeling. High-performance graphics display. Comprehensive detailing, dimensioning, and drafting. Integration with industrial design, engineering analysis, fabrication, NC programming, and more. All with an interface unmatched by our competition.

Plus, I/EMS gives you the freedom to choose from the industry's leading UNIX workstations, Intergraph CLIPPER and Sun SPARC.

Intergraph stands behind you. When you choose I/EMS, you're backed by Intergraph. We're a billion-dollar *Fortune 500* company. Our No. 1 customer satisfaction rating shows we understand your problems.

For more information, call 800-826-3515.

INTERGRAPH

Everywhere you look.

Intergraph® and CLIPPER® are registered trademarks and Everywhere You Look and I/EMS are trademarks of Intergraph Corporation. Other brands and product names are trademarks of their respective owners. Copyright 1992 Intergraph Corporation, Huntsville, AL 35894-0001. DDAD057A0

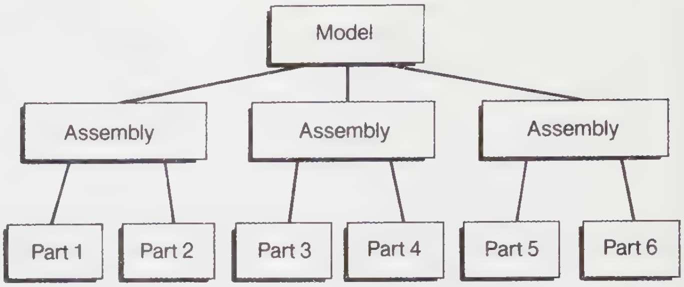
Circle 557

HIERARCHICAL VERSUS NETWORK DBMS

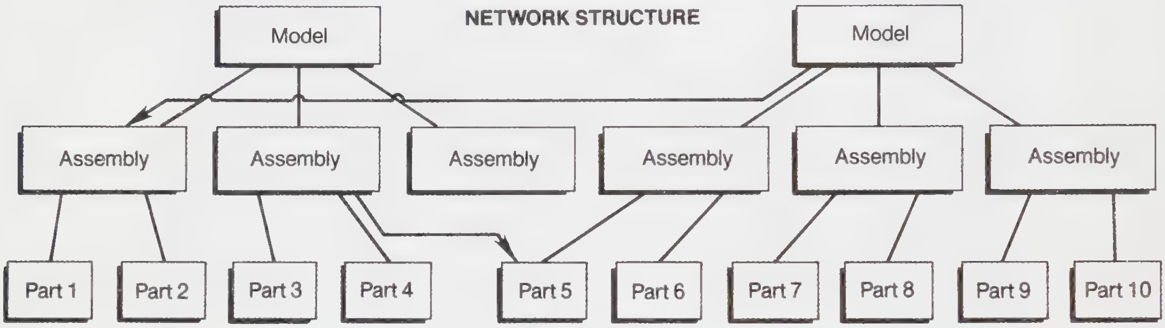
RELATIONAL STRUCTURE

Model	Assembly	Part 1	Part 2

HIERARCHICAL STRUCTURE



NETWORK STRUCTURE



The primary purpose of structuring databases is to formalize the relationships among data so the database can be queried logically. Most database manager systems (DBMS) are based around only one model type, but some DBMS combine aspects of all three.

In hierarchical databases, data records are stored in tree structures with branches connected by top-down links, or chains. Hierarchical management strategies are useful in situations where one data record, such as a part, is related to many data records, such as suppliers. The connection between records are clear cut.

Network databases are similar to hierarchical databases in that they are represented in tree structures. However, network schemes allow individual records to be linked laterally with any number of other records or files. They can represent many-to-many relationships, such as many parts built by many suppliers, rather than just one-to-many relationships.

Applying hierarchical or network data-management schemes to engineering data necessitates describing the relationships among data files clearly. This is difficult to do if unanticipated relationships, such as those between a model and its analysis data, develop. Hierarchical database models are inflexible because they are limited to tree structures. Because of the complexity of the relationships described, it is almost impossible to query a network-model database using nonprocedural, English-based query languages such as SQL.

Relational database schemes format information in tables composed of rows and columns. Each data file has its own table, where records are stored in rows that are a part of columns, or fields. Rows in tables need not be in special order, so information can be added easily to relational databases. Users of relational databases are not limited by inflexible links between data records — data are located using row-by-row searches.

However, relational database managers, because they involve extensive search procedures, can be slow. It is also difficult to adequately represent the many-to-many relationships found in engineering by using relational managers. However, the increased number-crunching power of many new computers, combined with better programming techniques used in database managers, have improved the speed of relational database managers. Also, special database machines can be used to increase search speeds.

ever, so until recently, this type analysis could not be done effectively because of hardware limitations. Often, engineers would assume flexibility and change accordingly the results of a rigid-body analysis, while at other times, a model is broken into parts, and bushings and springs loaded between the parts. Both these methods are considered inelegant and imprecise by experts.

Today, two methods are being used to model flexibility more accurately. One method uses finite-element data to model flexible structures, while another includes beam-element theory directly in the dynamic-simulation code. Using finite-element data to model flexibility requires conversion of data formats between the finite-element and dynamics codes. However, this method may be more accurate in some circumstances than the method that uses beam elements. Yet, analysis with beam elements may be faster and easier to implement.

Electronic design automation

One of the greatest benefits of electronic CAD (or ECAD) is the ability to forward and back annotate during de-

Sink your teeth into this...

Only SOLUTION 3000® takes you from concept to reality. Precisely.

Heard that one before? Sure you have. So don't take our word for it.

Ask the hundreds of companies—thousands of engineers and machinists—that use SOLUTION 3000 for their really tough jobs. People like automotive and aerospace tool and die makers. Consumer products engineers. Model makers. Mold and pattern makers.

They share alot in common. Tough problems. Like designing and machining parts that contain free-form sculptured surfaces. Analytical curve sweetening. Blending. Precise gouge-free machining of hundreds, or maybe thousands of surfaces at once. Automatically.

Straight talk.

Regardless of language. Sure, every CAD/CAM vendor "supports IGES". But aren't you tired of cleaning up data from inaccurate translations? SOLUTION 3000 communicates precisely with customers and in-house systems using CALS compliant IGES. Not to mention DXF, VDA-FS, GM DES, Chrysler CSF, and Ford FST (including surfaces).

Talk with our users.

Our customers will tell you that while all vendors promise service, we give it to them. Hassle-free. They'll tell you that SOLUTION 3000 is the first, best, and most fully supported solution for their complex surface design and machining CAD/CAM problems.

One thing they probably won't tell you, however, is how smart they are. Since SOLUTION 3000 is designed to run on either PC's or low cost workstations, they're spending under $6.00/hour* for an integrated CAD/CAM solution—compared to the $20.00/hour that some of their competitors spend.

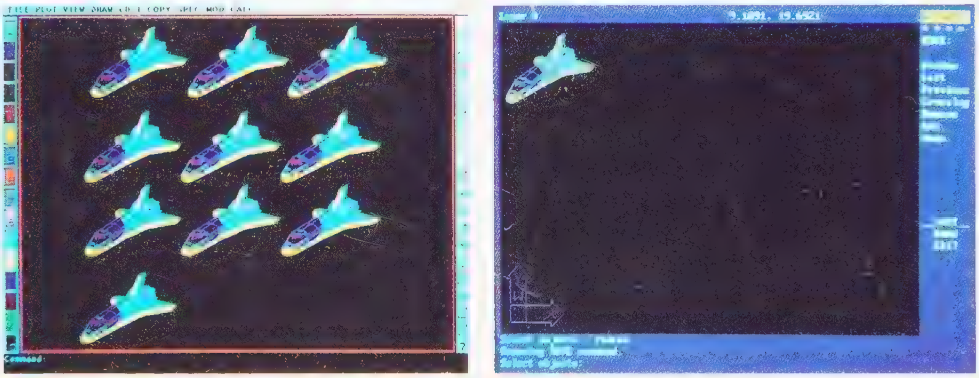
So write, fax or call and we'll rush a free brochure outlining SOLUTION 3000's capabilities. Or, we'll rush you a real rarity. A software engineer with chips in his shoes. Either way, we believe that what you see should be what you get.

micro engineering SOLUTIONS

26200 Town Center Drive
Novi, MI 48375
Office 313/347-9650
•
Fax 313/347-1893
•
Toll Free 1-800/832-9592

*Rate based on 55 hours per week. Cost amortized over 12 months.

The Fastest 386™ CAD!



FastCAD® regen of ten shuttles was 10 times faster than AutoCAD 386™

FastCAD Flies Past AutoCAD for Only $795

AutoCAD® claims their 386™ version solves the problem of slow regen times. If you think that makes them the fastest 386-optimized CAD on the market, think again. In side-by-side speed comparisons pitting FastCAD's optimized 386 version against AutoCAD's 386, FastCAD literally flies past AutoCAD.

With both programs running on a 386, FastCAD regenerated a drawing of ten shuttles 10 times faster than AutoCAD 386, and in some drawings the difference is even greater.

FastCAD burns speed, not money.

Written in assembly language for blazing speed, FastCAD is the undisputed 386 speed champion. It zooms the fastest. Pans the fastest. And draws the fastest. Period.

Equally important, FastCAD comes with productivity boosting features – like unique interactive windows, transparent icons, and exclusive plot assembly. FastCAD is loaded with features worth far more than the $795 price

If you haven't got time to waste, call (800)874-4028 now.

Contact Evolution Computing and we'll send you convincing information that will change your mind about CAD once and for all. You'll find out why FastCAD is consistently rated number one by the leading computer magazines. Why thousands of users won't settle for anything less than the fastest. FastCAD. *Anything less is a waste of time and money.*

EVOLUTION
FastCAD
COMPUTING
437 South 48th Street, Suite 106
Tempe, Arizona 85281-9936
Toll Free (800) 874-4028
Phone (602) 967-8633
FAX (602) 968-4325

Personal Computing Top Rated

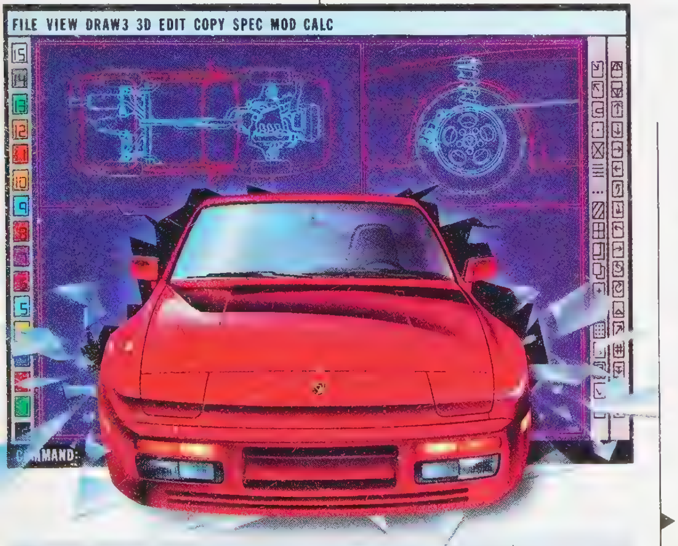
Best of PC Magazine

Timing tests were done on an ALR FlexCache 386 33 MHz machine with 4 MB RAM, DOS 3.3 and a standard VGA card. Drawings are shown after 74 seconds elapsed time.

©1991 Evolution Computing
FastCAD is a registered trademark of Evolution Computing
AutoCAD is a registered trademark of AutoDesk, Inc
AutoCAD 386 is a trademark of AutoDesk, Inc
386 is a trademark of the Intel Corporation

PhotoRealism in the Fast Lane.

Now FastCAD® 3D includes Pixar's RenderMan® for unequalled drawing speed, realism and ease of use.

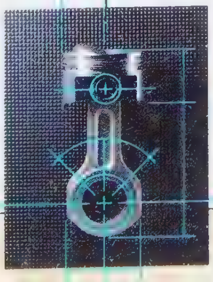

FILE VIEW DRAW3 3D EDIT COPY SPEC MOD CALC
COMMAND:

FastCAD RenderMan provides the CAD user with a realistic rendering solution by giving each object a surface appearance.

Models appear more realistic than they do in typical flat-shaded computer-generated images.

FastCAD RenderMan accepts three-dimensional geometry produced by FastCAD 3D, along with specified light sources and surface appearances, then creates the image.

The package includes surface appearances such as grass, carpet, wood, marble, plastic and metal.



▸ **Create your own surface appearances.**

To customize your FastCAD RenderMan appearances you can program your own in the C-like shading language. FastCAD 3D also uses surface appearances marketed by third-party RenderMan developers.

Add 3rd dimension without typing elevation.

FastCAD 3D's Depth Mode lets you place 3D points with the cursor. Select a point in one window, x-y for example, then use another window to move the point up and down in the z axis. Using windows as construction planes, you can draw or extrude in any direction. You can even draw from window to window.

▸ **Intelligent, mathematically defined entities enhance efficiency and flexibility.**

Revolutionary FastCAD 3D includes numerous entities such as solids, boxes, cylinders and domes. Plus, the program quickly creates chained cylinders, ruled and meshed surfaces, surfaces of revolution, Coons surfaces and more.

▸ **Animates and removes hidden surfaces faster than any 3D CAD.**

Get a clearer, more accurate overview of designs fast by filling surfaces and hiding objects behind them. Use FastCAD 3D Animate and Orbit commands to let you walk through or around your model.

FastCAD 3D comes with FastCAD RenderMan for incredible photorealistic renderings.

Call 1-800 874-4028 or write for the location of your nearest dealer and comprehensive FastCAD 3D information.

EVOLUTION
FastCAD 3D
COMPUTING

437 S. 48th St., Ste. 106
Tempe, AZ 85281-9936
Phone 602-967-8633
Sales 1-800-874-4028

©1991 Evolution Computing
FastCAD is a registered trademark of Evolution Computing
RenderMan is a registered trademark of Pixar and used under license by Evolution Computing

sign. For example, the engineer can specify critical circuit requirements on a schematic and forward annotate them to the layout designer. On printed-circuit board design systems, software is now able to transparently implement and check constraints such as minimum or maximum wire length, required via diameter, and net routing requirements. Once the design is complete, the design data can be back annotated to the schematic so that signal-delay analysis can be done.

Printed-circuit boards are getting smaller, but because of improvements made in packaging and layout technologies, they must hold an ever-increasing number of ICs. Efficiency of a PCB design system is now judged by the ability to generate a functioning, manufacturable board design.

Because of forward and back annotation, schematic capture — the entry of a conceptual design into the computer — and netlist extraction, which is the generation of a text file defining pin connections, are inexorably linked with PCB routing and placement. PCB design software can automatically place components based on the netlist. To compare the placement of components and gates, the CAD system counts the number of circuit crossings. Once placement is made, swaps of components, gates, and pins can take place. All swaps are made within design rules defined prior to placement.

Routing algorithms are used to make connections as defined by the netlist. A maze-search router can route a great percentage of the connections on most PCBs. Pattern routers are used to route regular areas such as memory arrays. Other programs can route diagonal bends in wires. Routing of diagonal bends is required to save board space and meet the speed requirements of some IC designs, such as those of emitter-coupled logic.

Depending upon the complexity of the board and the computational resources, routing may be 100%. Some systems do not route 100% of the connections, leaving perhaps a few percent of routes to be made manually.

Most routers define a 25 or 50-mil grid to ease the routing task. Some gridded routers permit traces off the grid to increase the number of successful connections. In contrast, gridless routers make interconnections without regard to a predefined space. A problem with gridless routers is that it is difficult to edit wires located on fine-grid increments. Multigrid and nonuniform grid methods allow route-channel saturation and relatively simple wire editing.

With automatic routing, routing time must be balanced with the percentage of routes completed. For example, it may be better to manually finish routing a board that has been 95% routed, a task taking a few hours, then to wait four or five days until the board has been entirely automatically routed. ■

RULES OF THUMB FOR EXPERT SYSTEMS

Many expert-system "shells" are available that allow users to develop expert systems for design. Experienced practitioners frequently offer a few general guidelines for evaluating and planning expert applications:

- **Narrow uses are best** — Programs that solve well-focused problems are the easiest to generate. Diagnostic programs are relatively easy to produce if the end result is the recommendation or selection of a single best alternative. If diagnosis results in a list of several possible candidates that must be evaluated, the program may need complicated rule-searching techniques.
- **Try some demo disks** — Several brands of expert-system shells are available in demo form for $20 or less. Many others come in scaled-down versions costing about $100. These programs often contain tutorial material as well. They provide an inexpensive means of comparing rule-based, fact-based, and example-based approaches.
- **Check interfaces** — Expert systems are increasingly used directly with spreadsheet and database files. But some expert shells access cells and records from the programs more easily than others. When evaluating a shell, thoroughly examine compatibility with the information that already exists in your company.
- **Get a feel for size** — Try to sketch the logical relationships of the rules and facts in the application. This will give an indication of program size while revealing redundant rules and missing information.
- **Beware of the expert** — Expert-system developers must work with a human expert to obtain the knowledge around which the program is based. If the human expert and the programmers do not communicate effectively with one another, the resulting program may be disappointing. When choosing project personnel, good interpersonal skills are just as important as technical skills.

FEA FOR THERMOPLASTICS

Generally, engineers have treated thermoplastic composites, which are often injection or compression molded, as isotropic. However, studies indicate that the fibers in injection-molded thermoplastics tend to line up in the direction of flow during processing. This means that parts have different properties in the flow direction than in the crossflow direction. These differences may not be taken into account in finite-element analysis of designs.

Stiffness and strength in the crossflow direction may be as low as 60% of that in the flow direction. However, most FEA of thermoplastic parts is based on material properties in the flow direction. Laboratory tests used to determine material properties give "best case" properties, or those in the flow direction. Designing with these properties without considering the opposing crossflow characteristics might lead to premature part failure.

Additionally, nonuniform orientation of short fibers during molding imparts anisotropic properties to a structure. Since finite-element programs assume certain basic material characteristics depending on how a structure is modeled, using isotropic elements to model anisotropic materials assumes erroneous characteristics. For example, assuming that a model of a thermoplastic composite part is isotropic will negate orientation effects, which could lead to underengineering the part.

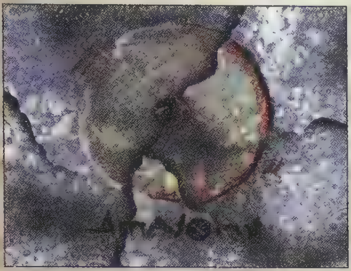
Another problem when analyzing injection-molded materials is determining the different material properties that develop in the part as it is filled. Analysts have recently begun using mold-filling programs to help preprocess data for finite-element analysis. The filling program will indicate the flow and crossflow direction for each element, which can help engineers determine the material properties to be applied at those elements.

Compression molding of newer continuous-fiber thermoplastics also poses analytical problems. Continuous fiber-reinforced thermoplastics generally have isotropic properties, but during compression molding they can develop resin-rich areas that affect part stiffness and strength. For example, experts found that T-type ribbing, which normally increases part stiffness, may not increase stiffness as much as expected because glass fibers may not fill the entire rib height. Continuous-fiber reinforcements in thermoplastics will fill long, thin ribbing about halfway during processing, leaving weak areas where strength is required. However, further analysis indicated that fiber fill of V-type ribs was more complete during compression molding.

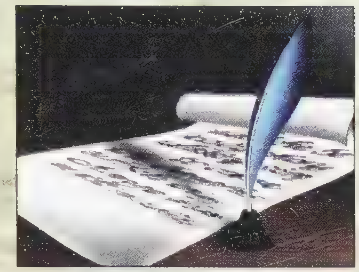
he Evolution of CAD

rom the beginning of time, we have tried to express ourselves through graphics.

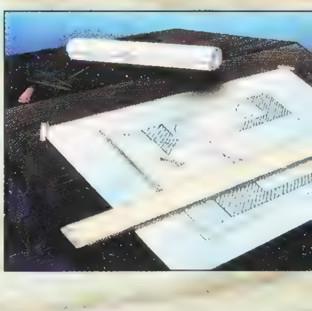
egin-
f time
e had
primi-
esign
r cre-
g any
pe of
phics.



In the 15th Century design tools were quill ink pens and crude styles of paper.



By the 18th Century we had advanced to the drafting table with T-squares, and the dreaded eraser.



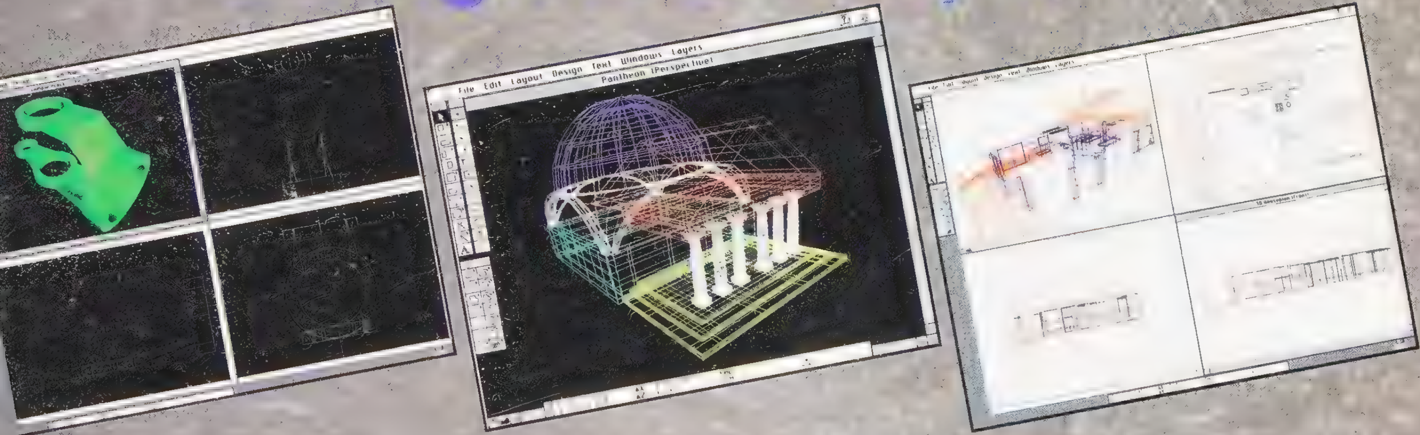
In the 20th Century the first CAD programs were very slow and extremely difficult to use, not to mention the expense of buying them.

As programs became easier to use, people thought they were radical and intelligent, but just lacked real CAD power.

Now step into the 21st Century...

DesignCAD 2D/3D

SYSTEM 7
COMPATIBLE



- 2D drafting
- ting Point Precision
- netric Viewing
- ociative Dimensioning
- rance options
- whead choices
- layers

- Import 2D drawings and convert them to 3D models
- Unlimited color Support
- Fast, Smooth 3D Shading in any view
- Specular Highlighting
- 3D Real-Time Rotation

- 3D Sculptured Surface
- Free-formed Spline Tools
- Automatic Hidden Line Removal in any View
- Perspective or Orthographic viewing
- Automatic Scrolling
- Symbol Libraries

- Import & Export PICT, DXF, IGES, XYZ Coordinates, & DesignCAD MS-DOS files
- Export RIB & EPS files
- FREE Plotter Support (Hewlett Packard & Houston Instruments compatible
- 500 FREE Symbols

all, fax or write for a FREE brochure & demo!

DesignCAD, Inc.
One American Way
Pryor, OK 74361
h: (918) 825-4848 fax: (918) 825-6359

$299

Circle 561

*"This is all the capability many designer
will ever need. Its price/performance rati
makes it a package we must recom-
mend."
([illegible] May 1992)*

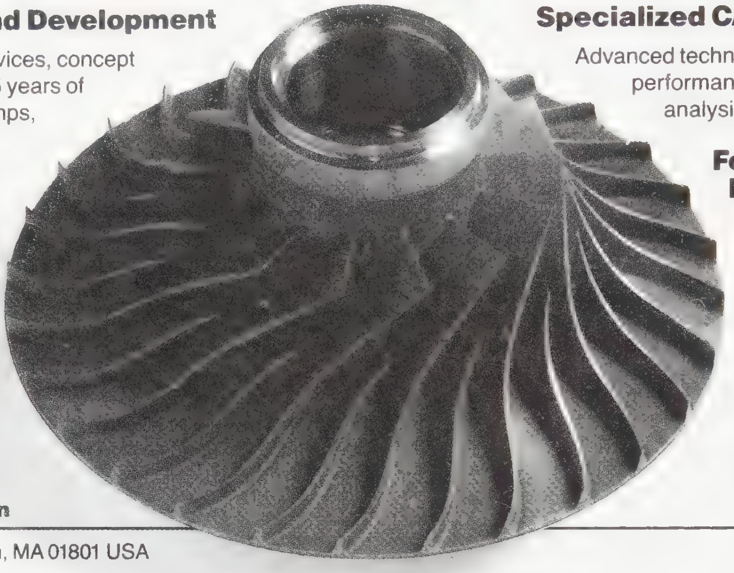
When it comes to driving turbomachinery development you'll find NREC behind the wheel.

Product Design and Development

Complete engineering services, concept through hardware. Over 35 years of successful designs for pumps, compressors, turbines, and combustors

Precision Manufacturing

Highest quality 5-axis machining of complex impellers, blades, and blisks, with fast production turnaround



Specialized CAE/CAM Software

Advanced technology software for design, performance prediction, vibration analysis, and N/C machining

For More Information

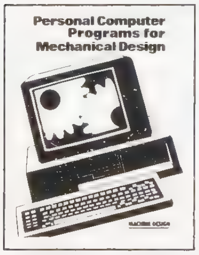
Please request our brochure or call Frank Hines at 617 937-4655

Northern Research and Engineering Corporation

NREC

39 Olympia Avenue, Woburn, MA 01801 USA

Circle 563



Personal Computer Programs for Mechanical Design

Design Engineers—Eliminate cumbersome calculations and save time with . . .

PERSONAL COMPUTER PROGRAMS FOR MECHANICAL DESIGN

This book is a compilation of math and mechanical programs that are written in basic programming language but may require some conversion for use with your particular computer. Review the book for 15 days and if not completely satisfied, return for full refund! Here is just a sampling of the programs included

- find roots of polynomials and fit general order polynomials
- evaluate significance of test data
- fit straight lines to data
- speed numerical optimization
- power shaft design
- software development
- optimum cost maintenance: corrective vs. preventive action
- calculating position & coordinate tolerances
- designing cams on a microcomputer
- special O-ring dimensions
- analyzing isothermal gas flow
  — plus more!

40 pages, softbound, $17.50. Quantity discounts for 2 or more copies.

Penton Education Division, 1100 Superior Avenue, Cleveland, Ohio 44114
800-321-7003 (in Ohio 216/696-7000)

Please send _____ copies of **PERSONAL COMPUTER PROGRAMS FOR MECHANICAL DESIGN.** I understand that I may review the book for 15 days and, if not satisfied, I may return it for full refund or credit.

☐ My payment is enclosed for postage-free shipment in the U.S. and Canada.

☐ Bill my company and include shipping and handling charges. My purchase order is enclosed.

Charge my ☐ Visa ☐ MasterCard ☐ American Express card.

Acct. No. Exp. date

Name

Company

Address (Not P.O. Box)

City State Zip

Signature

Penton Education Division, 1100 Superior Ave., Cleveland, Ohio 44114

Penton Education Division provides an easy way for you to learn the fundamentals of PERT (Program Evaluation and Review Technique) through a programmed-learning course.

PROGRAM EVALUATION REVIEW TECHNIQUE

This course covers:

The basic methodology of PERT.
Advantages and limitations of PERT as a management tool.
Preparing PERT charts for complex projects.
Developing time estimates for PERT activities.
Finding and manipulating the Critical Path of a project to save time and money in project completion.

Because this course is designed in programmed learning format, it can be completed in several evenings. You can choose your own time and place for learning, proceed at your own pace according to your comprehension.

Order **The Fundamentals of Pert** at $17.50 per course (plus state sales tax where applicable) by returning the coupon below with your check or company purchase order to:

Penton Education Division
1100 Superior Ave., Cleveland, Ohio 44114

Please send _____ copies of **The Fundamentals of PERT** at $22.00 each (plus state tax where applicable).

☐ Check enclosed.

☐ P.O. #_________ enclosed

Name

Title

Company

Address (not P.O. Box)

City/State/Zip

CAD peripheral hardware

The most widely used peripherals in CAD now include digitizers, plotters, color printers, and CD-ROM drives.

General-purpose PCs and workstations generally require additional hardware to handle CAD work. The most popular additions: large 19-in. or larger color monitors; digitizing pads and either a trackball or mouse for data input; plotters or color printers for output. Also rising in popularity as a CAD peripheral are mass-storage devices such as CD-ROM drives or tape drives for storing the increasingly large databases associated with engineering libraries.

Entering data

The most basic data-entry device is the keyboard. However, the increased use of graphic user interfaces (GUIs) has made the cursor-control mouse or trackball a necessity. The mouse or trackball is used to move a cursor on the computer screen to either make selections from menus or activate commands.

Mice or trackballs are also used to make simple or artistic drawings on computer screens. However, they don't have sufficient resolution to handle some of the more demanding data-entry tasks associated with CAD, such as picking up the precise location at points on engineering drawings. For that, CAD stations usually use digitizers — a tablet, pad and pen, or puck stylus — to draw or trace the graphics. The computer determines coordinate pairs from the digitizer output, and the graphics appear on the screen.

Digitizer menu selections can be made on tablet overlays or templates, some of which can be customized, or from screen menus. Some digitizers include a microprocessor to relieve the host CPU of some calculations associated with inputting drawings.

Resolution and accuracy are the two most important digitizer qualities. Resolution, the smallest detectable movement, is measured in points or lines per inch and ranges from 100 to 1,000 lines/in. You'll pay more for high-resolution digitizers and they are slow because each coordinate pair requires more information. However, high resolution is necessary for drawings requiring great accuracy. Digitizer accuracy usually ranges from ±0.015 to ±0.025 in. but varies with temperature, humidity, and the klutziness of the individual user.

Digitizers use several sensing methods, the electromagnetic method being most common. The stylus generates an out-of-phase magnetic field sensed by a wire grid in the tablet. Electromagnetic digitizers are not affected by conductive materials, temperature, or humidity, and they do not require calibration. Also, they are not harmful to magnetic media like floppy disks, and they permit resolutions up to 1,000 lines/in.

The magnetorestrictive method uses the puck or pen to pick up a current pulse from the wire grid,, but it is unpopular because the tablet must periodically be rebiased with a large permanent magnet.

Restrictive sensing requires contacts on the tablet edges to detect the current drop from pulses sent by the stylus. This permits use of a transparent pad that can be placed over drawings to be traced.

Electrostatic digitizers have an electric field between the stylus and a special surface containing a printed circuit, Mylar antenna, or grid. The stylus typically uses a 50 to 100-Hz sine-wave signal picked up by uniform x and y direction lines in the antenna. Electrostatic devices are not affected by physical shock or acoustic noise, but they cannot be used with conductive materials and can be affected by moisture.

In charge-ratio digitizers, the grid is laid out in a nonuniform pattern. This creates different signal component ratios. It requires less circuitry and is less expensive than other electrostatic methods.

Sonic digitizers use a stylus with a sound generator. Strip microphones along the edges of the tablet pick up the periodic sounds. Sonic digitizers can work on any flat surface. Electrical and magnetic interference do not affect these digitizers, but ambient acoustic noise may. Sonic digitizers are also available for 3D applications.

Some 3D digitizers use electromagnetic sensors mounted on nonmetallic objects to update position and orientation of the input device. Others use precision potentiometers in joints to determine up to seven Cartesian-coordinate set positions per second. A linking program allows users to feed an object's coordinates directly to CAD packages.

Increasingly popular desktop digitizers overcome a problem that engineers face when using complex CAD software, mainly that pull-down menus are often cumbersome and time consuming. Using templates that are placed over a digitizer, engineers can simplify the process of calling out commands.

Large-format, or stand-alone, digitizers are also growing in use. Engineers can use these electronic drafting boards to enter complex E-size drawings accurately and easily. They make updating older drawings simpler as well. Function keys allow the boards to emulate all major software formats.

In contrast to digitizer tablets, most mice are mechanical, sensing movement by measuring the distance and direction of a rolling ball or wheel. Some use optical systems that bounce light beams off a special gridded surface or mouse pad. Mice are relative-distance devices; they do not give absolute position, so their accuracy is limited. However, for simple jobs not requiring digitizer accuracy, the less-expensive mouse can be adequate. Developers are working to overcome the accuracy-reducing limitations of mice, including low resolution and "skipping."

Among the recent advances in cursor control technology is the cordless mouse. Cordless mice have two infrared bulbs and a recharger cord socket rather than a cord. The infrared receiver mounts near where the mouse will be used. Cordless use requires an overnight charge, but the unit can be used with the cord plugged in.

Mice often have suspension systems, on-board microcomputers, and self-contained drive mechanisms. Suspension systems provide traction on many surfaces at any angle.

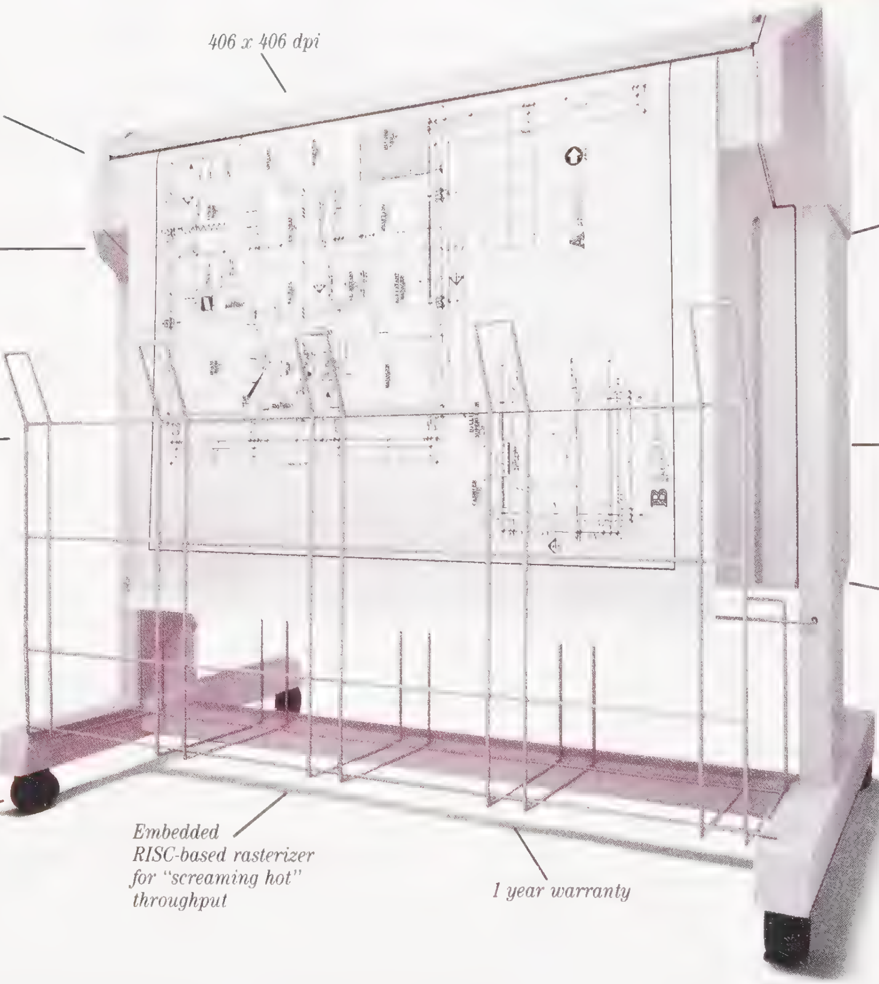
Trackballs have a ball-and-socket construction. A user rolls the ball with the fingers or palm. The cursor moves in the direction of roll at a rate proportional to rotational speed.

An operator must rely heavily on tactile sense when using a trackball because there is no correspondence between cursor position and the ball. Tracking devices are preferred by some

Now!
Direct Imaging
on Vellum.

Hotter Plotter.

Introducing DrawingMaster Plus


406 x 406 dpi
24" and 36" sizes
"Archive" quality plots ideal for diazo or photo reproduction.
Connects up to 4 PCs, workstations or mainframes.
No toner, ribbons, pens or chemicals.
Automatic Media Cutter
One or two color output
New DirectWrite™ DTV Vellum media.
Embedded RISC-based rasterizer for "screaming hot" throughput
1 year warranty

CADALYST MAGAZINE HIGHLY RECOMMENDED
1990

Awarded "Highly Recommended" rating by CADalyst Magazine

DrawingMaster™ Plus is hot to plot.

In fact, it was specifically designed to run with the fastest CAD systems–taking just minutes to do jobs that take pen plotters hours.

And high throughput doesn't mean low resolution. At 406 X 406 dpi, you get exceptionally clean lines that rival laser and electrostatic plotters.

For fast checkplots, select QuickPlot® mode and cut plotting time almost in half.

While DrawingMaster Plus is hot, complicated it's not.

There are no pens, no toner and no chemicals involved. You simply load a roll of paper or film and plot–more than 50 E-sized plots completely unattended.

DrawingMaster Plus is exceptionally reliable too. Plus it's backed by a standard one year on-site warranty.

And no other 406 dpi plotter comes close to DrawingMaster Plus in price.

Warming up to our new hot plotte
For more information and our new F
Guide to Media, call us today at:
800-932-1212.

We draw on your imagination.™

CalComp
A Lockheed Company

©1991 CalComp. DrawingMaster, QuickPlot, DirectWrite and We draw on your imagination are trademarks or registered trademarks of CalComp
CalComp, P.O. Box 3250, Anaheim, CA 92803. In Canada, call: 416-635-9010

Circle 565

LASER VERSUS IMPACT PRINTING

Developments in dot-matrix technology today are generally aimed at high-speed continuous-form printing and other areas where laser capabilities are either particularly expensive or unavailable. For high-quality output, desktop models use 24-pin print heads to produce near letter quality output at a price below that of laser printers. Low-end laser printer prices are on the order of $1,500. Higher printing speeds and on-board page description languages that enable laser printers to generate various fonts boost price. As an example, 18-page-per-minute units can cost about $8,000. Nevertheless, laser printers offer a variety of benefits. They generate images using the same electrophotographic process employed in office copiers. Models costing under $5,000 can noiselessly churn out up to eight pages of text each minute. Lasers have fewer moving parts than impact printers and are highly reliable. The main replaceable component is a toner cartridge.

Typical laser printer resolution is 300 dots per in. (dpi), though 400-dpi units are becoming more widely available. At least one manufacturer has developed a machine with 600-dpi resolution ($15,000). Printers with even higher resolution are under development.

One trend is for some electronics and software to migrate from printers onto PC motherboards. It is possible to find plug-in PC cards that hold memory and a page description language for laser printers. Installing this electronics in the PC allows speedier information transfer to the laser printer and may eventually reduce printer costs as well.

Color laser printers differ from black-and-white units in that they must repeat the electrostatic imaging process four times, once for each base color. This makes these devices considerably more complicated than black-and-white laser printers and more expensive as well. Typical prices are around $40,000 or more.

Printers that can also serve as copiers are starting to appear. One such device is a PostScript-compatible laser printer that sells for below $5,000. Another 6 page/min. laser printer, priced at below $2,000, includes plain-paper fax capabilities as a $600 option.

operators because of the tactile feedback provided by ball momentum. Older trackball designs tended to be inaccurate, but were effective for tracking, following, and pointing at moving elements displayed on the screen.

The mechanics of early trackballs left something to be desired, though their internal components would break easily if dropped. Recent designs improve accuracy and are more reliable.

Touch-screen displays are becoming increasingly popular as data-entry devices. They offer high immunity to contaminants and are user friendly.

Two types of touch screens — mechanical and optical —- are used in CAD/CAM systems. The mechanical type is a transparent screen overlay, which detects the location of the touch. Optical touch screens use rows of light emitters and receptors mounted just in front of the screen, with the touched location determined by which beams are broken.

Mechanical systems can detect the position of a touch to a high resolution (down to 0.01 in.) but slightly reduce the light output of the display. These devices are more suitable for cursor control in some systems. Resolution for optical systems is low, equivalent to the spacing of the optical components, typically about 0.1 in. Optical systems are best for menu selection rather than for precision cursor control.

Joysticks and voice data-entry devices are seldom found in CAD/CAM. Joysticks are potentiometric devices usually found in consumer products such as video games. Voice data-entry has yet to catch on in CAD, mainly because most commercial systems still understand only a limited number of words. However, these devices are more common in factory applications. They can be used to increase operator productivity in selecting menu items.

Hardcopy

Plotters have been the mainstay output device for graphics. But printers are gaining more graphics capabilities.

Four basic types of printers are available — impact, electrostatic, ink jet, and thermal. Impact printers use small hammers or a printhead containing small pins to strike a ribbon to form dot-matrix images. Colors are introduced through the use of multiple ribbons or single ribbons with several different color bands. Color intensity is limited by the pigments used in the ribbons. Also, creating hues or shades is almost impossible.

Copy quality is also low with 9-pin dot-matrix printers because they have relatively low resolution. Impact printers are most suitable for high-speed, low-cost, high-volume hardcopies. Typical applications include line printing of text data such as bills of material. However, newer 24-pin dot matrix devices approach near letter-quality resolution. Some of these devices have graphic capabilities and can produce letter-sized drawings with resolutions approaching that of 300 dot/in. laser printers.

Electrostatic printers have electrodes that put a programmed set of point charges onto dielectric paper. The paper then passes through a toner applicator. Toner is attracted to, and fused onto, the charged areas, producing an image. Electrostatic printers can make black-and-white copies, producing fast, high-resolution images. They are also capable of producing halftones used in printing. But electrostatic printers are large and cumbersome, expensive, and require toner maintenance and handling. Electrostatic printers are best used in the production of large, complex output. More recently, color electrostatic copiers have been developed. Although these units also produce fast, high-resolution output, they are relatively high priced.

Ink-jet printers produce images by propelling fine droplets of ink onto the medium to be printed. Droplets can be generated in continuous streams or pulses. In continuous-stream printers, droplets are propelled between charged plates. Digital inputs determine which droplets are charged and which are not. The charged droplets are returned to the ink reservoir, while uncharged droplets continue to the printing surface where they form dots to construct characters, symbols, and graphics. With pulsed or on-demand ink-jet printers, a programmed matrix of dots is generated as needed to form images.

Continuous-stream printers create many more ink droplets per second than pulsed printers; thus, they produce higher-resolution images. But a required ink-recirculation system is messy and easily contaminated. Some ink-jet printers have automatic head-cleaning systems to overcome this drawback. Ink-jet printers are suited for small-format, moderate-quality, fast-turnaround applications with paper or transparencies.

Thermal printers use heated wires or nibs to produce images. The nibs trans-

While Our Competitors Are Diligently Trying To Emulate The SummaSketch® II…

We Proudly Announce SummaSketch II *Plus*

The world's best selling, most emulated, most acclaimed desktop tablet just got better. We've taken SummaSketch II, the industry standard, and added several new features to create a tablet that is, unquestionably, the world's best.

Unlike some competitors, we put everything in the box—4-button cursor *and* 2-button stylus (or 16-button cursor), interface cables and a utilities diskette with Windows® 3.0 and ADI® drivers. Plus we've added things like 2000 lines per inch resolution and 10 mil accuracy—standard. Plus the fastest, easiest set-up and configuration procedure. Plus an offer for a free AutoCAD® or CADKEY® Master Template (a $245 value). Plus software compatibility with over 400 programs, and hardware compatibility with PCs and Macintosh.® Best of all, it's still 100% pure SummaSketch—the editor's choice, winner of every major editorial accolade for graphics tablets. And the people's choice, with well over one-half million sold to demanding computer graphics professionals.

Every decision should be this easy. In fact, the only tough decision is which Plus to choose: 12″ x 12″ or 18″ x 12″ Professional. For literature, or the name of your local dealer, call 1-800-729-7866. For technical information call 203-881-5400.

PC MAGAZINE EDITORS' CHOICE November 28 1989 SummaSketch I

CORPORATE SATISFACTION POLL TOP RATED PC WEEK 1990

CADENCE BEST OF 1990

CATALYST MAGAZINE HIGHLY RECOMMENDED 1990

Summagraphics®

Every decision should be this easy.™

© 1992 Summagraphics Corporation. Seymour, CT 06483. All rights reserved.

Why experienced designers have designs on our new Summagrid® III.

Construction. 7

Sharp edges or recessed areas can damage drawings. Summagrid III has a rugged, one-piece construction with rounded edges. And it's light enough for easy field use.

6 Compatibility.

Summagrid III is compatible with PCs, Macintosh®, workstations and over 400 software programs. And our utilities diskette includes an Autodesk® ADI® driver, Microsoft® Windows™ 3.0 driver and Microsoft Mouse emulation.

5 Performance.

With 10 mils accuracy and up to 2000 lpi resolution, Summagrid III has been created for maximum compatibility with CAD/CAM/CAE, architectural, facilities management and cost estimating applications.

4 Complete Package.

Watch out for hidden costs. Optional cursors, cables and utilities diskettes can add hundreds to the price of your tablet. Summagrid III comes complete including a choice of 4- or 16-button cursor, or 2- or 3-button stylus.

3 Warranty.

PRIORITY 48 HOUR RESPONSE

Summagrid III is covered by our comprehensive one-year warranty program, including Priority Response™. If you encounter a problem in the first 90 days that cannot be resolved over the phone, we will ship you a permanent replacement unit in 48 hours (U.S. only).

2 Price.

$1999*

Get the most tablet for your money. With our optional low-cost stand — and no hidden costs for accessories — Summagrid III is, by far, the best value on the market.

#1 Seller.

Go with the best. Summagrid III is made by Summagraphics, the world leader in tablet sales and technology. For more information, send for our free Large Tablet Buyer's Guide, or call 1-800-729-7866 and ask for the name of your nearest dealer.

Summagraphics®

Every decision should be this easy.™

* Suggested U.S. list price – 18" x 24".

©1992 Summagraphics Corporation. All rights reserved.

FREE! Large Tablet Buyer's Guide.

Send me a copy of *"How to Decide on a Large Tablet"* and the name of my local dealer.

Name: ____________________ Title: ____________

Company: ____

Address: ____

City: ____________________ State: ____ ZIP: ___ ________

Tablet Application: ________________________________

Mail to: Large Tablet Buyer's Guide, Summagraphics Corporation,
Sixty Silvermine Road, Seymour, CT 06483

SCANNING FOR CAD APPLICATIONS

In the early days of CAD, the tried and true method of transforming data from blueprints into a CAD/CAM database was to manually digitize every point on the drawing through use of a digitizing pad. Optical-scanning techniques are a big improvement over this painstaking process. Scanner technology can be four to eight times faster than manual digitizing.

Data scanners change the drawing into raster data and convert the raster data into vector information that can be understood by CAD programs. Some systems will also distribute the scanned and converted drawings directly to the engineer.

The simplest systems really are high-tech approaches to manual digitizing. With this approach the drawing is displayed on a raster screen. There are CAD-like commands for overtracing the raster image with vectors. An advantage of the approach is that it uses colors to show the operator whether each element of the drawing is digitized correctly.

A second method uses electronics that tries to recognize drawing entities in the raster pattern, then automatically converts these to combinations of vectors, geometric patterns, symbols, and ASCII text. Currently, no scanning and conversion system recognizes all entities automatically. Each drawing takes some interactive editing, either at an edit station within the scanning system or in a CAD program.

Vectorization can happen in several ways. For example, one system uses dedicated hardware to convert raster data to short vectors that only the scanning system understands. These vectors then must be ordered into a format that can be translated into data for CAD programs. Another system needs constant operator intervention to produce the desired vector file. Each system requires specially trained operators, and each drawing takes several hours of expensive system time to convert.

Older vector scanning technologies could not handle text and symbols. But scanning technologies now incorporate hardware that compares pixel patterns to standard forms to find a match. However, pattern matching is compute-intensive and there are still glitches. Connections between specific features in the drawing may be dropped, for example. Therefore, the converted drawing still must be edited interactively.

Another approach uses rule-based software to recognize symbols, text, and geometry. The processor can be preprogrammed to accept specific types of data from several types of media including aperture cards. For instance, if a drawing contained no text, the system could be tuned to translate geometry and symbols. The ability to fine tune the computer to specific types of data can eliminate the need for constant operator interaction with the system.

Use of parallel processing reduces compute time from hours to minutes. And once drawings are translated, they can be off-loaded to PCs for editing. However, recent advances in raster-editing tools may make vectorization unnecessary.

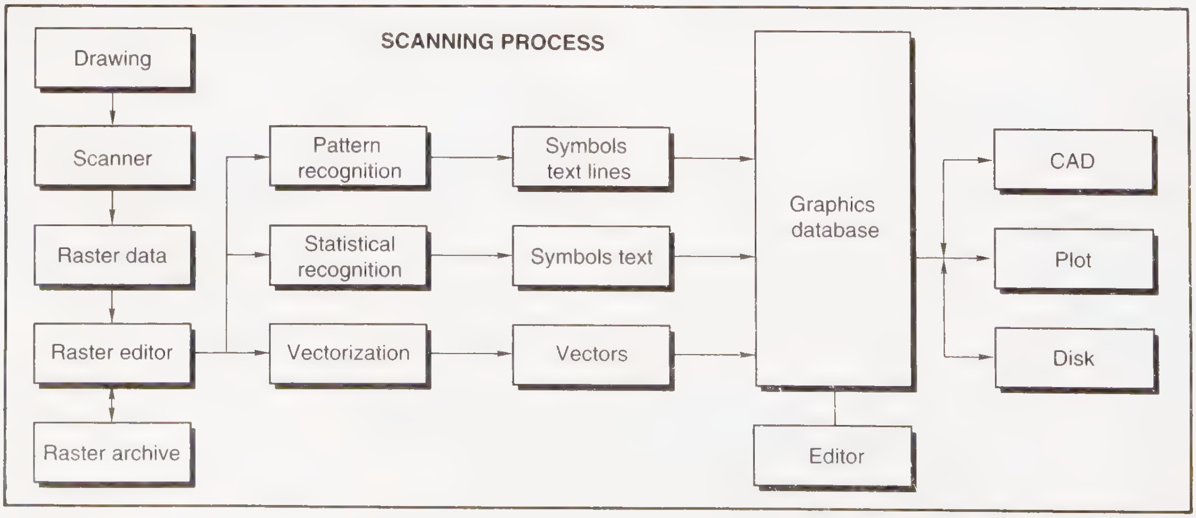
Numerous scanners for reading color images into the computer are available for handling legal-size and smaller documents. Price depends primarily on the resolution, but other factors are involved as well. For example, one $2,500 device for Macintosh computers provides a 2,400-dpi resolution for line art and 600 dpi for color and gray-scale information. It connects to the host via a SCSI port and works with a palette of 16.8 million colors.

Another page scanner costing about $6,000 can process 25 pages/min. at 200 dpi and is designed for electronic publishing applications. It can scan in documents at steps between 200 and 400 dpi or 64 gray-scale steps. An optional image processing board allows single-pass imaging of documents containing both text and gray-scale information.

In contrast, a production-volume large-format (handling 40-in.-wide drawings) scanner in the $25,000 range provides true 400-dpi resolution, interpolated 800-dpi resolution, 8-bit 256-level gray-scale capability, user selectable resolutions from 1 to 800 dpi and throughput of less than one minute for 36 × 44-in. drawings scanned at 200 dpi.

Other scanners are optimized for digitizing film negatives and color slides. One such unit costs about $10,000 and has an adjustable scanning resolution from 150 to 4,800 dpi. Image data can be captured at either 48 bits/pixel or 24 bits/pixel, and images can be scanned in at a rate of about one per minute. The unit connects to either PCs or Macintosh computers via a separate interface board or a SCSI interface.

Handheld scanners are also available. These devices typically sell for about $500 and up, depending on whether or not they handle color, and are designed for gathering images for uses such as illustrations in brochures. One such device scans a width of a little over 4 in. at 200 dpi in color mode and 400 dpi in gray-scale resolution at the rate of one line every 4 ms. Controls include contrast and brightness. Simple image editing software is often included in the price.



HI JetPro®. A day's work in under an hour.

9:00 AM

CAD Plots

No more waiting for pen plotter check plots. HI JetPro Series V100 creates HP-GL™/2, HP-GL and DM/PL™ CAD "review plots" at 360 dpi in under five minutes! Includes real and protected mode ADI® drivers.

9:05 AM

A- to C-Size FAX Output

JetPro outputs your FAX/modem files directly for high-resolution A- to C-size plain paper copies. Optional sheet feeder for A- and B-size output.

9:10 AM

Spreadsheets

C-size and rollfeed capability allow you to create large, readable spreadsheets. Driver is available for Windows™ 3.0 compatibility.

9:15 AM

Multiple Review Copies

For meetings create A-size review copies in one minute; high-quality, C-size review copies in under five minutes.

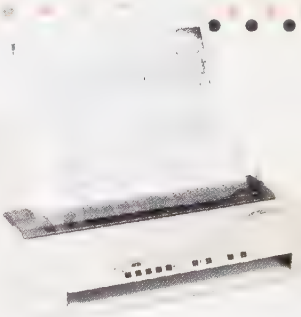
9:30 AM

Documents

JetPro emulates the IBM® Proprinter™ XL24 to create high quality reports and letters from a wide range of word processing packages.

9:35 AM

Scanner Output



Automatically reads and outputs high-resolution, scanned, raster images from hand-held, desktop and large-format scanners. At a fraction of the cost of electrostatic plotters.

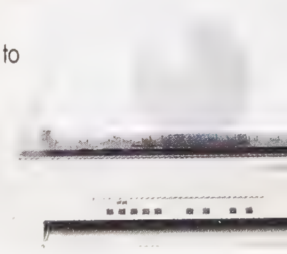
9:40 AM

Project Schedules

Standard rollfeed accessory allows long project management charts to be plotted from rolls of standard or translucent bond paper.

9:50 AM

Presentation Charts



There's even time left to do large-scale charts for a 10:00 AM presentation. For information on the HI JetPro Series V100 plotter, or the name of your local dealer, call 1-800-444-3425.

Circle 567

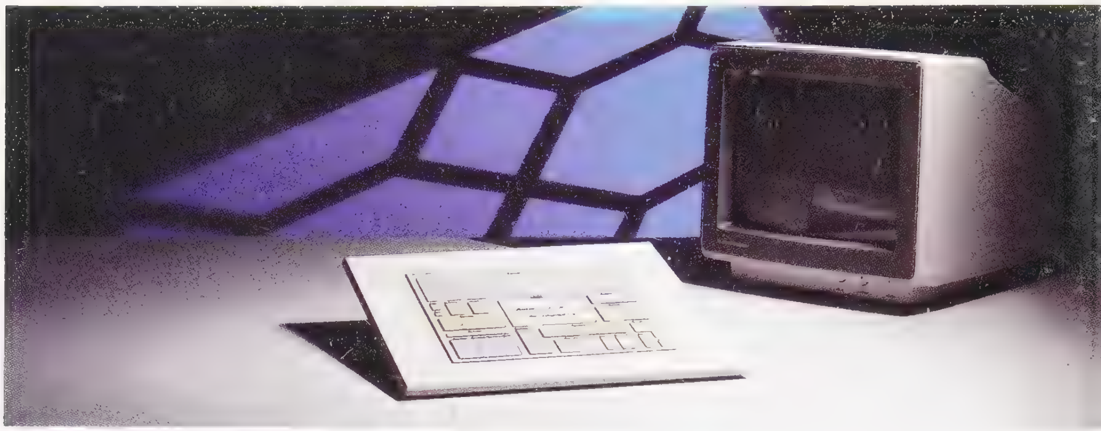
New HI JetPro® Series Model V100.

HOUSTON INSTRUMENT®

Every decision should be this easy.™

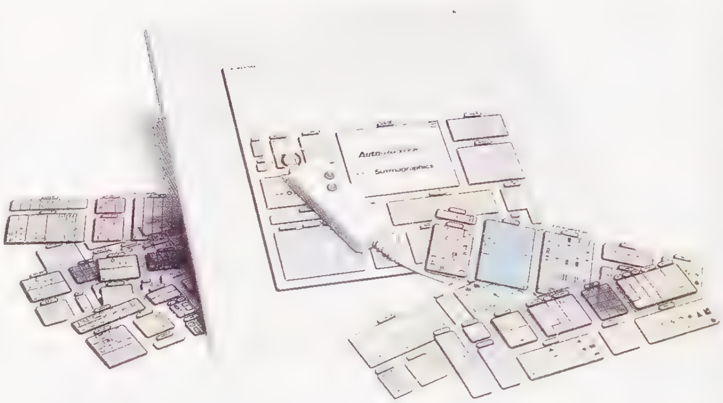
© 1992 Summagraphics Corporation. Seymour, CT 06483. All rights reserved.

Summagraphics® Subtemplates



Summagraphics Subtemplate Series

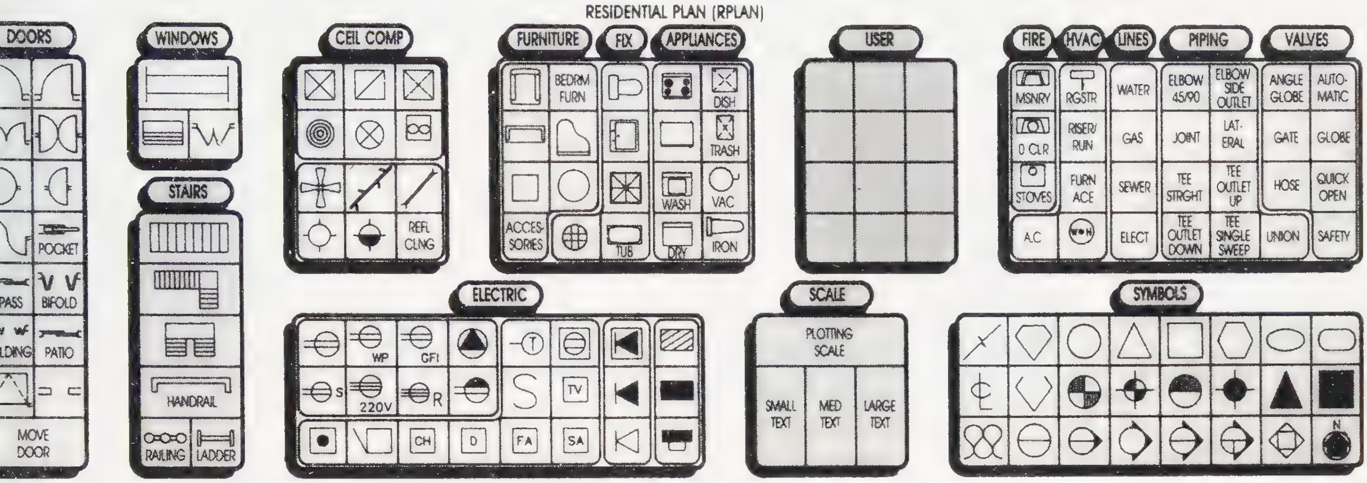
- Comprehensive symbol library subtemplates for use with AutoMASTER™, KeyMASTER™ and VersaMASTER™ Master Templates
- Modular design of Master Templates makes adding subtemplates easy
- Compatible with AutoCAD®, CADKEY®, and VersaCAD®.



Summagraphics®

Every decision should be this easy.™

Summagraphics® Subtemplate Series for use with our AutoCAD®, CADKEY® and VersaCAD® Master Templates.



nmagraphics, the world's leading manu-
turer of graphics tablets, now offers a com-
te CAD library of Master Templates and
nbol library subtemplates for use with
toCAD, CADKEY and VersaCAD software.
u may receive a free Master Template of
ur choice by returning the "Free Template
fer" coupon inside a SummaSketch® II Plus
SummaSketch II Professional Plus box (offer
od in North America only). Subtemplates
d additional Master Templates may be
rchased using the attached order form, or
calling 1-800-444-3425.
Summagraphics Master Templates and
nbol library subtemplates help increase
oductivity in several ways:
aves Time—puts hundreds of logically
grouped commands in view at one time, no
earching through nested screen menus to
nd the right command
Accurate—symbols and illustrations are in
roper scale and proportion
ersatile—your Master Template can be
ustomized to meet your specific application
equirements with a variety of modular
ubtemplates.

ubtemplates are available for:

toCAD (AutoMASTER™)
- esidential Plan
- ommercial Plan
- rchitectural
andscape
- Mechanical Fasteners
- Electrical
- Residential Elevation
- Commercial Elevation
- Mechanical Detail
- Electronic Schematic

ADKEY (KeyMASTER™)
- rchitectural Plan
- Mechanical Detail
- lectronic Schematic
- Architectural Elevation
- Mechanical Fasteners

rsaCAD (VersaMASTER™)
- esidential Plan
- Mechanical Detail
- rchitectural
andscape
- Residential Elevation
- Mechanical Fasteners

Each subtemplate contains symbol libraries for a specific application as follows:

Subtemplates for Architects

Residential Elevation
- cabinets
- appliances
- hatches
- chimneys
- fixtures
- shutters and windows
- attic vents
- scale
- doors
- stairs

Residential Plan
- doors
- windows
- stairs
- ceiling components
- electrical symbols
- furniture
- fixtures
- appliances
- scaling
- fireplaces
- H.V.A.C.
- lines
- piping and valves

Commercial Elevation
- handicap fixtures
- windows
- hatches
- doors
- elevators
- linetypes
- welding

Commercial Plan
- doors
- windows
- stairs
- reflected ceilings
- elevators and escalators
- linetypes
- base grid generator
- scaling
- fixtures
- welding symbols

Landscape
- sprinklers
- vehicles
- hatches
- sports
- parking lots
- trees
- figures
- fixtures
- fencing

Electrical
- ANSI standard symbols
- receptacle outlets
- lighting and fluorescent outlets
- communication systems
- signaling systems
- ceiling grid generator
- annotation symbols
- conduit and duct generator
- switches
- motors and transformers
- panels and phones

Subtemplates for Mechanical Engineering

Mechanical Fasteners
- bolts
- drives
- nuts in plan view
- studs
- washers
- annotation
- nuts in profile
- tap screws
- set screws
- screws

Mechanical Detail
- forms
- break
- scale
- annotation
- tolerances
- welding
- datum target
- general dimensioning

Subtemplate For Electronic Drafting

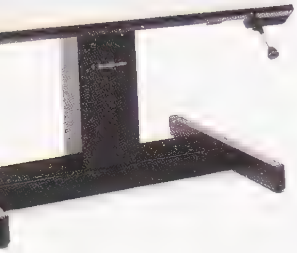
Electronic Schematic
- logic
- fundamental
- connectors
- scale
- motor and generators
- acoustical devices
- lamps
- switches
- antennas, attenuators, batteries, and delays
- transformers, inductor windings, and vacuum tubes
- resistors, capacitors, and thermocouples
- semi-conductors and fundamental components

HOUSTON INSTRUMENT   Summagraphics

8500 Cameron Road, Austin, TX 78753
(800) 444-3425 or (512) 835-0900   FAX: (512) 835-1916   TELEX: 776438

For a free Supplies and Accessories Catalog call 1-800-444-3425.
Circle 568

Microgrid® III



Microgrid III Graphics Tablets:

- High accuracy, high performance tablets for GIS/mapping, electronic publishing and CAD applications
- Accommodates drawings from A through J sizes
- Autodesk® ADI®, Microsoft® Windows 3.0 and mouse drivers
- Compatible with major graphics software programs
- Tested for guaranteed accuracy with our automated laser interferometric system.

Summagraphics®

Every decision should be this easy.™

MICROSOFT™ WINDOWS™ COMPATIBLE

Microgrid® III.
High accuracy, high performance large format tablets.

e Microgrid III Series consists of six large size blets (17″ x 24″ through 44″ x 60″) that can ndle A- to J-size documents. High precision ecifications make Microgrid III tablets ideally ited for demanding applications such as GIS/ apping, electronic publishing, CAD and more.

uality Construction

Rugged, durable ABS non-glare work surface
Thin (1.5″), lightweight construction with one-piece top surface and rounded edges
Optional stands:
– Tilt stand for 17″ x 24″ and 20″ x 20″
– Power or manual lift stands for larger models.

xclusive Accuracy Testing

icrogrid components are tested several times uring assembly. To guarantee accuracy, each blet is tested on our exclusive automated ser interferometric system.

recise Input

Standard accuracy of 0.005″ (0.002″ optional)
- Up to 2000 lines per inch resolution
- Choice of transducers
  - – 2- or 3-button stylus
  - – 4-button cursor with cross-hair sight
  - – 16-button cursor with cross-hair sight and magnifier for the most demanding digitizing
  - – Optional stylus and cursor holders can be mounted on either side of the tablet for easy access
- Dual transducer flexibility
  - – Allows stylus and cursor to be simultaneously active, providing on-demand change of transducers.

High Performance Features

- Multiple Output Format: Summagraphics Microgrid UIOF, MM (SummaSketch®), and other major formats ensures compatibility with major software programs
- Programmable features: Set baud rate, output format, resolution, origin location and transducer to meet your specific needs
- 16-bit processor
- Skew correction
- Built-in ADB™ device that lets you connect to Macintosh® II, SE and LC computers.

Utilities Diskette

- Autodesk® Device Interface® (ADI®) driver
- Microsoft® Windows 3.0 driver
- Tablet.com™ driver with Microsoft Mouse emulation
- Diagnostic test, reset and configuration software.

Support

- One-year limited warranty; 90-day on-site warranty available.

---

icrogrid III Specifications

ctive Area and hipping Weight:	20″ x 20″ (508mm x 508mm) – 35 lbs (15.91kg) 17″ x 24″ (423mm x 610mm) (A2) – 35 lbs (15.91kg) 24″ x 17″ (610mm x 432mm) (A2) – 35 lbs (15.91kg) 24″ x 36″ (610mm x 914mm) (A1) – 55 lbs (25kg) 36″ x 48″ (914mm x 1219mm) (A0) –90 lbs (40.91kg) 44″ x 60″ (1118mm x 1524mm) – 110 lbs (50kg)
andard ccuracy:	0.005″ (0.127mm); 0.002″ (0.05mm) optional
esolution:	Up to 2000 lpi (80 lines per mm)
oximity:	Up to 0.5″ (12.7mm)
chnology:	Electromagnetic
rmats:	Microgrid UIOF, MM (SummaSketch), and other major formats
terface:	Dual RS232-C and Dual ADB
Cables:	10′ RS232-C cable with 25 pin D female connector for IBM-PC and compatibles; 25 to 9 pin adaptor for AT compatibility
Transducers:	2-or 3-button stylus and 4- or 16-button cursor. Optional 3x magnifier for the 16-button cursor.
Data Rate:	Up to 166 reports per second
Baud Rate:	Selectable up to 19.2K Baud
Power Supplies:	Wall mounted 115 VAC 60 Hz, 100 VAC 50/60 Hz, 220 VAC 50 Hz, 240 VAC 50 Hz
Certifications:	UL, CSA, TUV, VDE, FCC Class B and tested to IEC ESD and Immunity standards
Environmental:	Operating: 45° F to 110° F (7° C to 43° C) Storage: -45° F to 145° F (-43° C to 63° C) Relative Humidity: 8% to 90% non-condensing

Specifications subject to change without notice.

Summagraphics®

Every decision should be this easy.™

Sixty Silvermine Road, Seymour, CT 06483
(203) 881-5400 TELEX: 964348
FAX: (203) 881-5367

1992 Summagraphics Corporation. All rights reserved.

For a free Supplies and Accessories Catalog call 1-800-444-3425.

For more information contact:

1-800-243-9388 (U.S.) or 1-800-729-7866 (Canada)

ASIA-PACIFIC REGION
Seymour, CT
(203) 881-2000 FAX: (203) 881-5367

EUROPEAN REGION
London, England SW7 4HA
4471-244-7733 FAX: 4471-244-8584

SummaSketch® II Plus

SummaSketch II Plus desktop tablets:

- The world's best selling tablet
- Everything in the box
- Compatible with over 400 software programs
- 2000 lines per inch resolution; 0.010" standard accuracy
- Autodesk® ADI®, Microsoft® Windows 3.0 and mouse drivers
- Lifetime limited warranty.

Summagraphics®

Every decision should be this easy.™

SummaSketch® II Plus.
For IBM® PCs and compatibles and major workstations.

MICROSOFT® WINDOWS™ COMPATIBLE

nmaSketch II Plus is the latest generation he best selling SummaSketch family and overwhelming choice of computer graphics fessionals. It comes with everything you need fast and accurate digitizing, tracing, drawing, strating, cursor steering and menu picking h your CAD or other graphics programs.

e Industry Standard

Over one-half million sold, more than any ther tablet
Vinner of major editorial accolades.

e Most Software Compatibility

ompatible with over 400 software programs
he most widely emulated format in the industry.

Complete Package

hoice of active areas–Standard 11.7″ x 11.7,″ nd 18 ″ x 12″ Professional version for pplications requiring larger work areas

- Wedge-shape design–For comfortable desktop use
- Lightweight–For use in your lap
- Choice of transducers
  - – 4-button cursor with cross-hair sight for accurate digitizing and a 2-button stylus for drawing or illustrating
  - – 16-button cursor is also available.
- Utilities diskette
  - – Autodesk® Device Interface® (ADI®) driver
  - – Microsoft® Windows 3.0 driver
  - – Tablet.com™ driver with Microsoft Mouse emulation
  - – Diagnostic test, reset and configuration software.
- Interface cables and power supply
- Template Offer–Order form is enclosed for a free AutoCAD® or CADKEY® Master Template (small handling charge).

Specifications

- Up to 2000 lines per inch resolution
- Standard 0.010″ accuracy
- ½″ proximity, allows you to trace documents up to ½″ thick.

Optional Configurations

- 16-button cursor with 11.7″ x 11.7″ or 18″ x 12″ tablet
- Macintosh® version with ADB™ interface for compatibility with Macintosh II, SE and LC computers

Lifetime Limited Warranty

- Lifetime on tablet, two-year warranty on accessories (US and Canada only).

---

mmaSketch II Plus Specifications

ive Area:	11.7″ x 11.7″ (297mm x 297mm) 18″ x 12″ (458mm x 305mm)
ndard curacy:	0.010″ (0.254mm)
solution:	Up to 2000 lpi (80 lines per mm)
ximity:	Up to 0.5″ (12.7mm)
hnology:	Electromagnetic
rmats:	MM (SummaSketch) and Microgrid UIOF
vers/ lities:	Autodesk Device Interface (ADI), Tablet.com (Microsoft Mouse emulator), Microsoft Windows 3.0, Reset, Test and Send.com
erface:	RS232-C
bles:	25 pin D female connector for IBM-PC and compatibles; 25 to 9 pin adaptor for AT compatibility

Transducers:	2-button stylus and 4-button cursor, or 16-button cursor
Data Rate:	Up to 113 reports per second
Baud Rate:	9600 Baud or Autobaud
Power Supplies:	115 VAC 60 Hz, 220 VAC 50 Hz, 240 VAC 50 Hz, 100 VAC 50/60 Hz
Certifications:	UL, CSA, TUV, VDE, FCC Class B and tested to IEC ESD and Immunity standards
Environmental:	Operating: 45° F to 110° F (7° C to 43° C) Storage: -45° F to 145° F (-43° C to 63° C) Relative Humidity: 8% to 90% non-condensing
Shipping Weight:	11.7″ x 11.7″ – 10 lbs (4.54kg) 18″ x 12″ – 14 lbs (6.36kg)

SummaSketch II Plus is also available for the Macintosh SE, II, and LC.
Specifications subject to change without notice.

Summagraphics®

Every decision should be this easy™

Sixty Silvermine Road, Seymour, CT 06483
(203) 881-5400 TELEX: 964348
FAX: (203) 881-5367

© 1992 Summagraphics Corporation. All rights reserved.

For a free Supplies and Accessories Catalog call 1-800-444-3425.

For more information contact:
1-800-243-9388 (U.S.) or 1-800-729-7866 (Canada)

ASIA-PACIFIC REGION
Seymour, CT
(203) 881-2000 FAX: (203) 881-5367

EUROPEAN REGION
London, England SW7 4HA
4471-244-7733 FAX: 4471-244-8584

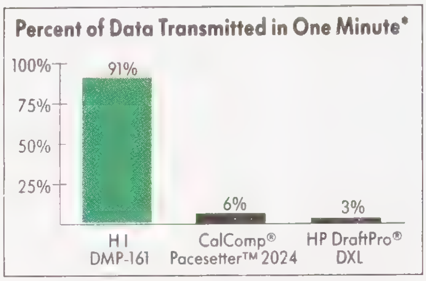
Our New DMP™-160 Ser
# of Four Plotters, a Sc

Never before has one family of plotters done so much, so fast, and so well.

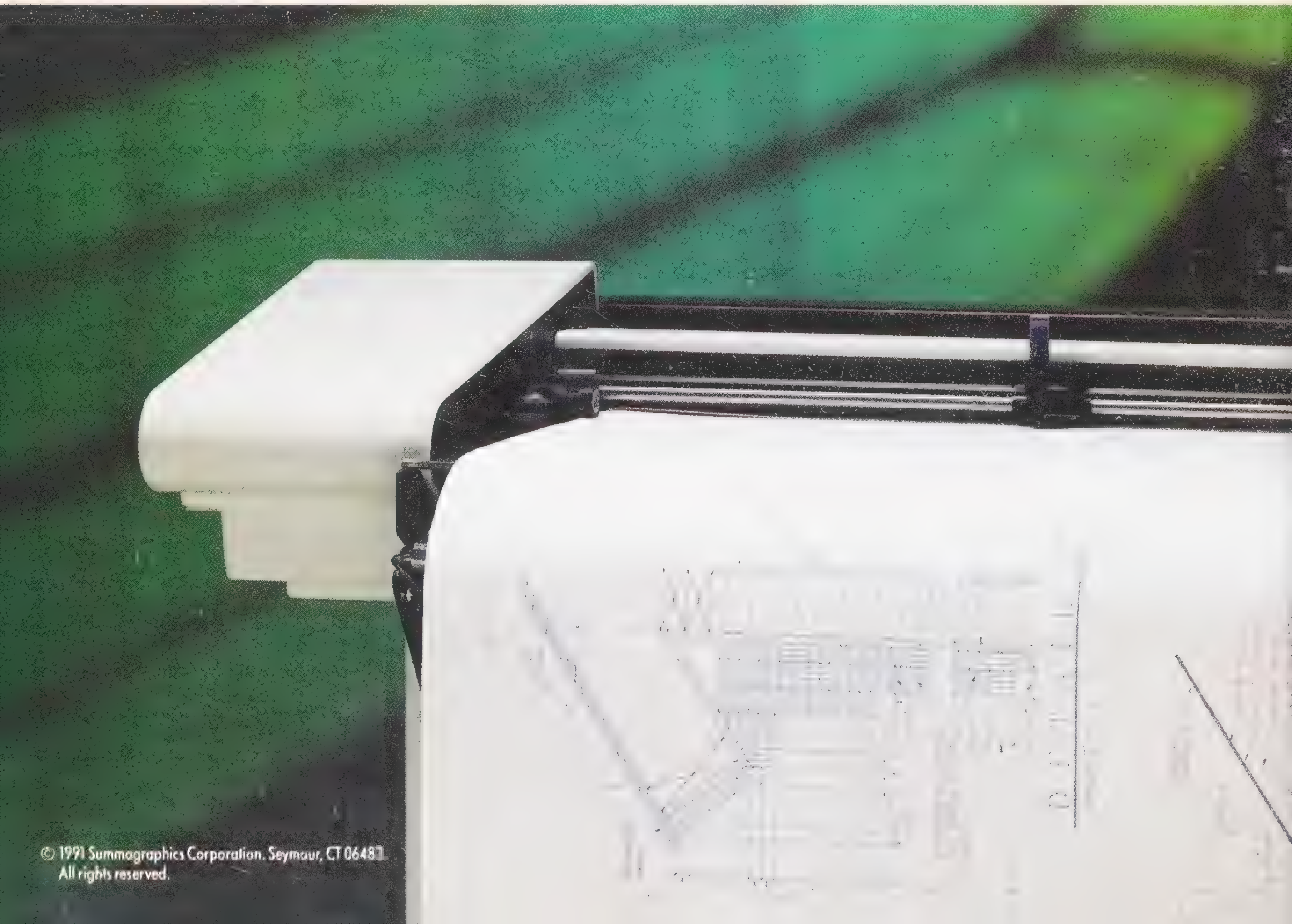
The new Houston Instrument DMP-160 Series Plotters are here. Now you can send four plots or more to a DMP-160 Series Plotter in the time it takes to send just one to other plotters. The DMP-162R is the only plotter at its price that delivers unattended plotting during the busy workday—or late into the night. And all DMP-160 Series Plotters can be converted into sophisticated wide-format scanners. In less than sixty seconds.

Now One Plotter Does the Work of Four.

Compare our new series to anything else in their category. You'll find our D- and E-size plotters are the only ones that include the new, highly compact HP-GL/2 plot language and 512K standard memory. That's the equivalent of 2 MB on other plotters—or four times the memory at one-fourth the cost. And they're the only ones that can be expanded to 4 MB, or the equivalent of 16 MB! So instead of tying up you and your computer during long or multiple plots, our new plotters release your equipment fifteen to thirty times faster than the competition.



* Using *CADalyst's* test drawing (4775.DWG) on a Compaq® 386/16MHz. Plotters were set to manufacturer's recommended settings.



© 1991 Summagraphics Corporation, Seymour, CT 06483.
All rights reserved.

s Plotters Do the Work
ner and a Night Shift.

Increased AutoCAD® Productivity. These new plotters arrive AutoCAD ready with ADI® drivers which allow you to harness and use the full productivity features of the DMP-160 Series.

Set-It-and-Forget-It Unattended Plotting.

Our DMP-162R E-size plotter comes with 1 MB of memory and an automatic rollfeed and cutter system for hours of unattended plotting—ideal for network, multi-user or heavy plotting requirements. This workhorse does it all: Configures your plotter directly from your PC or Macintosh® with our Hot-To-Plot™ programs. Stores up to four different user configurations. Uses a pen grouping feature for up to eight times the pen life. And cuts and gathers plots in a catch-basket for immediate access—no waiting for a batch of plots to be finished. Just load a 150′ roll of D- or E-size paper, push a few buttons and go back to work. Or go home.

Turn Your Plotter Into a Scanner.

Only Houston Instrument offers the optional SCAN-CAD™ accessory and software that allows a DMP-160 Plotter to double as an affordable, large format scanner. That in itself saves 80% of the cost, and all of the floor space, of a stand-alone scanner.

Every Decision Should Be This Easy.™

See the new DMP-160 Series today. And find out what it's like to go home early at night. For information, or the dealer in your area, contact Houston Instrument at 1-800-444-3425.

HOUSTON INSTRUMENT®
A Summagraphics Company

Circle 571

fer pigments from a wax-impregnated sheet onto specially treated paper. For color production, the paper makes three passes under the thermal head: one for each primary color. Thermal printers offer fast print times and are quiet, but resolution is low. The least-expensive units use a 9-pin dot-matrix pattern. Also, the cost of the special paper is higher than that for normal paper, and roll storage and disposal can be a problem.

Two basic types of electromechanical pen plotters are used in CAD/CAM systems. In flatbed *X-Y* plotters, servocontrolled pens or styli move in two axes over flat, stationary sheets of paper. In drum or roll plotters, pens, styli, or ink jets remain stationary or move along one axis while the paper moves in another axis on a revolving drum.

Although many types of plotters are now available, the pen plotter is still the most widely used peripheral in CAD applications. For instance, one large vendor of turnkey CAD systems sells 10 pen plotters for every thermal plotter.

There are many reasons why pen plotters are widely used. They are fairly easy to use, offer high-resolution plotting, and handle a variety of output sizes. The media required for pen plotting are inexpensive. In addition, prices have dropped because of competition and improved manufacturing techniques.

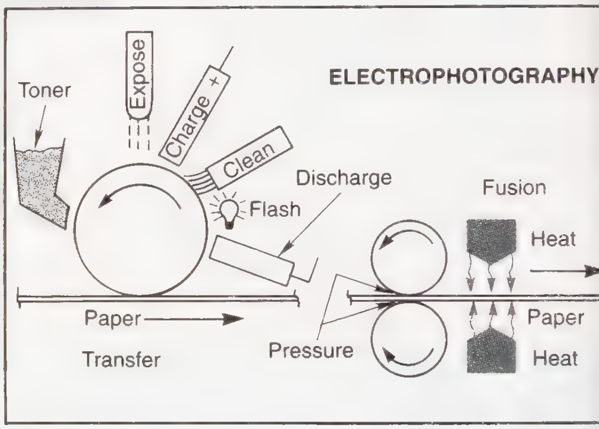
Speed, however, has always been a problem with pen plotters. The speed of a plotter is controlled by several factors, but the main property which limits plotter speed is the mechanical time constants and inertia associated with the components that actually move the pen.

Vendors have increased the speeds at which plotters accept and process data. For instance, vendors have begun using 32-bit microprocessors to process vectors. A 32-bit processor allows plotters to process short vectors up to 250% faster than previous systems. Internal pen-sorting and pen-control algorithms on new plotters eliminate unnecessary pen movements to increase plotting throughput.

Improvements are also being made in plotter mechanics. For instance, some plotter turrets have automatic pen capping. The turret pen holder eliminates side-to-side movement by allowing automatic pen changes over the plot surface. It also makes possible the simultaneous use of a variety of pen types in the turret. An optical sensor determines which type of pen is being used, and turret electronics adjusts pen performance parameters automatically.

LASER PRINTING

About eight steps produce a print in a laser-based plotter. The drum surface is charged and exposed to a laser or other high-intensity light source. Toner clings to drum areas exposed to light and is transferred to paper. Heat and pressure from rollers fuse the toner to paper. Charge is then removed from the drum surface and it is thoroughly exposed to mask remaining or latent images. Finally, the drum surface is cleaned before recharging.



COLOR PRINTING

Color thermal-transfer printers with PostScript compatibility today are available for about $5,000 whereas they cost closer to $25,000 only five years ago. And ink-jet color printers today can be had for under $1,000. Ink-jet printers are the prevailing technology for low-end color printing. All colors are placed in a single pass of the printhead, thus giving good registration. Unfortunately, plain bond paper tends to wick up the color ink, reducing the color saturation and blurring the image somewhat. Thus, ink-jet devices generally must use a special clay-coated paper to get good results.

Thermal-wax transfer technology printers yield better results but cost more, usually in the $5,000 to $15,000 range. Again, they require special paper to get the best results.

Dye-sublimation technology is a relatively new technology that produces photographic quality results. It uses a transfer ribbon containing a dye that actually sublimates, or changes from a solid to a gas when heated. The gas is then absorbed into the surface of photograph-like paper. Printers in this category carry costs in the $10,000 to $25,000 range.

Another new color printing technology is called phase-change ink jet. It provides image quality that approximates that of color laser printers. Typical costs are below $10,000. It also does not need special paper. It uses dye-based inks diffused into wax color sticks that are solid at room temperature. The printer heats up the sticks in a reservoir. A printhead that operates analogously to that of an ink-jet head ejects droplets that solidify as they hit the paper.

Because the ink is solid as it hits the paper, there is no wicking. A pressure-fusing process smooths the solidified color dots and insures bonding to the paper or film.

The way paper is held in plotters can affect plot speed and accuracy. In flatbed plotters, the paper must be held securely in place because any movement or irregularity in the paper surface can ruin the plot. Electromagnetic attraction is the most common hold-down method in CAD-quality plotters. In this method, an electrostatic charge attracts the paper and holds it securely over the entire surface, thus preventing slippage or bubbling.

Roller mechanisms of various types are used to control the media in other pen plotters. In some plotters the paper is held with clamps and moved back and forth over a drum. In others, pinch or grit wheels on both sides of the paper control paper feed. Plotters based on pinch wheels require smaller motors. However, drum-type plotters may hold paper more securely, eliminating unwanted media shift.

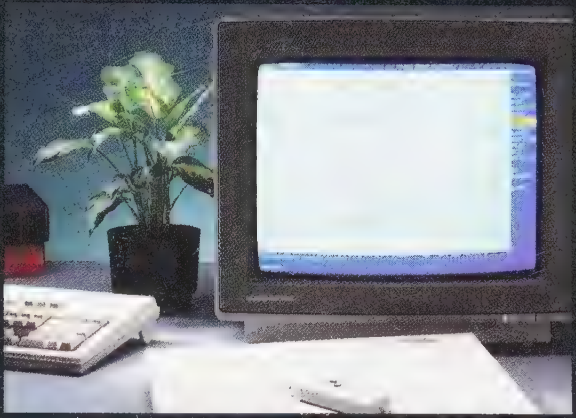
Plotter resolution is controlled both mechanically and in software. Mechanical resolution, which is controlled by motors, is the shortest distance a plotter can move its pens. Plotters controlled by dc servomotors provide the best resolution, while those controlled

NEW LDS™ 4000 PLUS SCANNER

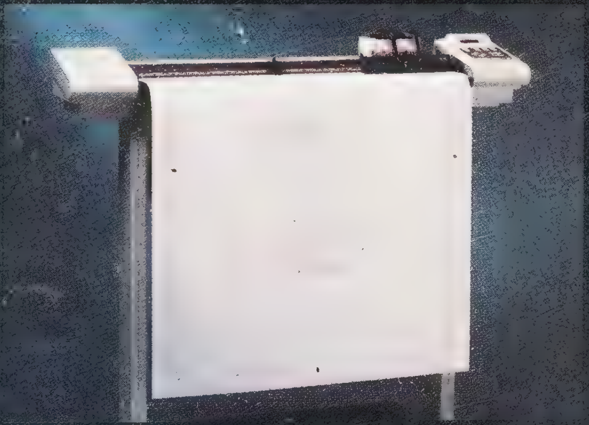
Scan it. Accurately scan a typical E-size drawing in seconds; create a raster file that can be displayed in most major PC-CAD programs.

Store it. Hold and manage thousands of documents on your optical or hard disk, protect against loss or damage and eliminate expensive storage costs.

Retrieve it. No more searching for hours in the storage room. Access and view all or part of your document quickly on your PC.



Change it. With optional software, display a raster (dot) image in your CAD program, then overtrace it and create a vector (line) image.



Plot it. Once scanned by the LDS 4000 Plus, you can print your document on a raster printer or plot your overtraced vector image on a plotter.

FREE LITERATURE

Please send me information on the benefits of scanning, featuring the new LDS 4000 Plus Scanner (Fill in or attach your business card).

Name: ______________________

Title: ______________________

Company: ______________________

Address: ______________________

City: ____________ State: ____ Zip: ________

Phone: ______________________

Mail to: LDS 4000 Plus, Houston Instrument, 8500 Cameron Road, Austin, TX 78753. Or call toll-free: **1-800-444-3425**

Do it. Send for our free information on the capabilities of the new LDS 4000 Plus Scanner, and how it can change the way you manage paper drawings.

HOUSTON INSTRUMENT.
A Summagraphics Company

© 1991 Summagraphics Corporation,
Seymour, CT 06483 • All rights reserved.

Images courtesy of Image Systems Technology

Circle 572

by stepping motors provide more coarse resolution.

Addressable resolution is controlled by software and is the smallest movement that can be specified in the plotter program. According to experts, addressable resolution is usually equal to mechanical resolution unless the mechanical resolution is so fine that plotter throughput would be adversely affected by making them equal.

Both large and small-format pen plotters are available for CAD/CAM. Small-format units plot A through C-size drawings, while large-format units handle D and E-size plots. Large-format plotters are considered the workhorses of CAD/CAM. However, with the increased use of personal computers, small-format plotters, which often can be placed on desktops, are growing in popularity. More recently, vendors have introduced plotters that will handle a variety of sizes.

Plotters are usually connected to PCs through serial or parallel interfaces. The most common personal computer serial interface is RS-232, while the most common parallel interface is Centronics. Minicomputer-based systems and workstations are often connected through interface buses. In addition, plotters have built-in graphics command languages that help them translate graphics output into a format the plotter can accept. Today, there is no standard graphics command language, although HPGL may be a *de facto* standard.

Pen plotters are being replaced in smaller formats. Applying technologies such as laser and thermal transfer to narrow-format plotters, which can handle A or B-size drawings, results in plotters that can perform several functions. Newer technologies produce reports as well as CAD drawings, a feat pens cannot match.

Two examples of narrow-format machines include one based on dot-matrix technology, giving high-quality color prints with 720-dpi resolution for about $3,000, and a laser that can print at 17 pages per minute. HPGL/2 vector graphics let the device print from nearly any CAD package.

Some predict thermal technologies will unseat other technologies in the long run. Direct thermal printers may soon have raster-to-raster capability.

Thermal-transfer printers already lead the market for small-format imaging. Dye-diffusion, on the other hand, offers perhaps the first truly photographic output from a CAD/CAM system. However, costs of up to $75,000 for a machine that produces a 17-in.-square image limit these printers to solid modeling and rendering applications, where reproduction quality is a premium.

Lasers, too, have their place in the CAD/CAM market. Currently, small-format monochrome lasers are coming on strong, thanks to their quality, price, and ability to use plain paper. Color lasers, currently available in A or B-size, may also be contenders as they come down the price curve. Most lasers contain HPGL emulation, turning them into plotter-capable printers, but these are almost exclusively A-size.

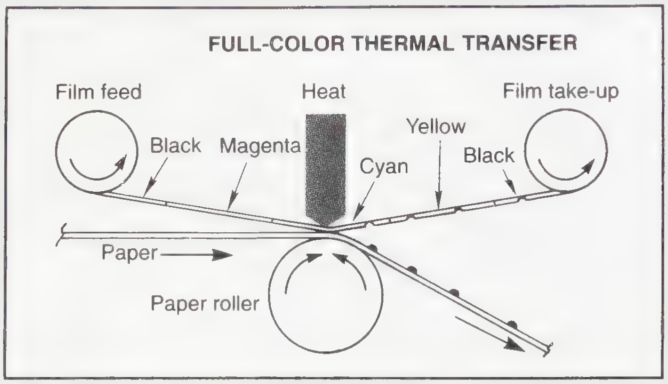
The choice of output device may depend heavily on acceptable copy quality, which is generally given in terms of clarity and precision. Although resolution is often given in "dots per inch" or "addressable points per inch," the number of lines is the important consideration in determining copy quality. The best way to judge line quality is by comparing output samples of products using application software. Look for straight lines, smooth curves, and lines that connect where they should. Resolution depends on software support as well as features of the printer or plotter.

Speed and frequency of hardcopy production are also important factors. Often counted as inches per second or gs of acceleration, the number of pages produced per unit time is the best way to compare devices. When all relevant

THERMAL TRANSFER PRINTING

Printing an 8¼ × 11-in. color picture with the thermal-transfer process requires four 8¼ × 11 sheets of waxed ribbon. In the process, heat fixes an area of colored wax to the paper, and the ribbon is peeled away. The process is repeated four times on a sheet of paper to produce a full-color image. Mixed colors are produced by overlaying one semitransparent wax over another. To yield a broader selection of hues, more sophisticated systems, such as D2T2, allow varying the wax dot size.

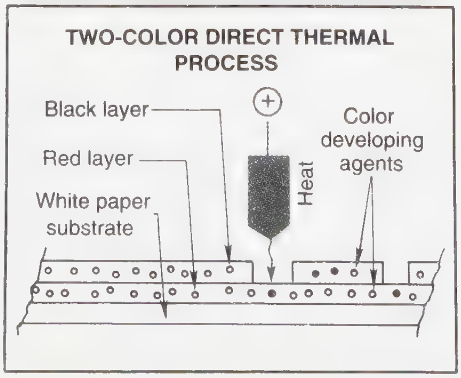
Thermal transfer is one solution for full-color, small-format printers and plotters. The devices are compact, quiet, easy to use, and affordable. They do their job on the desktop better than other devices can.



DIRECT THERMAL PRINTING

The secret to thermal printing is the paper. Color-developing agents embedded in layers on the paper's surface respond to heat. Two-color plotting is done when the heater burns through the first layer on the paper to expose color-developing agents in the layer below.

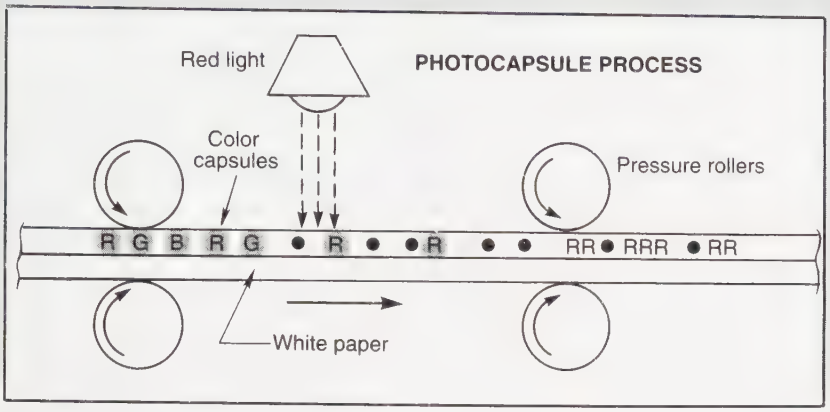
The technology has not yet been used in four-color applications, and is currently limited to one or two-color printing and plotting. Direct-thermal technology may yield better color, especially for fax and label-printing applications. Besides simplicity, the technology offers speed and silence.



PHOTOCAPSULE PRINTERS

Photocapsule printers use film embedded with droplets of color dyes in light-sensitive microcapsules. The film is exposed to light, but instead of reacting with silver-halide crystals in the emulsion, the light causes capsules of the same color to harden. Developing brings the film into contact with paper under enough pressure to break the capsules that have not been hardened, releasing a portion of the colored dyes.

The technology is similar to that used in producing photograhic prints in color, but without the liquid chemicals. The technology has several advantages, such as good image quality, cleanliness, and speed. On the downside are its high paper and film costs. However, media costs will come down if more paper vendors start producing the necessary media. So far, the technology has been used to print color pictures from 35-mm slides, but not to plotting.



speed factors are taken into consideration, CRT copiers are the fastest, pen plotters and camera systems the slowest, and impact and electrostatics printers in between.

In addition to the price of the equipment, total cost of an output plotter or printer includes materials used in the production process — media, pens, ink, toner, film — and service contract costs. Electrostatic printers and camera systems are the most expensive, impact printers the least expensive, and CRT copiers and pen plotters in the middle. When total system cost is considered, based on an average order quantity of supplies, camera systems cost the most per copy, pen plotters and impact printers cost the least, and CRT copiers and electrostatic printers are in between.

Terminals

Most interactive CAD/CAM systems use raster-scan or vector-refresh terminals, though raster-scan is by far the most common. These types produce images through the same basic cathode-ray tube (CRT) principle. In a glass-enclosed tube, a finely focused electron beam is deflected onto a phosphor-coated screen. The screen then glows to produce a visible trace when excited by impinging electrons. Differences in qualities such as cost, resolution, color, animation, and brightness make each of the three types of terminals best for certain CAD/CAM applications.

Raster-scan terminals produce images with a matrix of picture elements called pixels. In color screens, each pixel consists of a set of red, green and blue dots called a triad. Typically, pixels are each illuminated to one of 64 intensity levels to produce a viewable image with various gray levels. As in commercial television, an electron writing beam is swept, or rastered, across the entire screen line by line from top to bottom. A modulated signal changes the beam intensity at the proper points on the screen to selectively illuminate each pixel according to a pattern stored in memory, which may be in a separate computer or at the terminal itself. Each displayable pixel requires at least one corresponding bit in memory, which is sometimes called a bit map. The screen is scanned in this manner 60 times per second to update the image before the phosphor coating fades.

Resolution is an important consideration in raster terminals. Screen resolution is defined by the number of horizontal pixels times the number of vertical pixels. Higher-resolution screens of 1,000 × 1,000 or more are often used in CAD/CAM applications to reduce jagged appearances of lines that are at angles other than horizontal, vertical, or 45°. However, the more resolution an image has, the more memory and processing time is required to support it. The falling cost of memory and

PENCIL PLOTTERS

For check plots, drawings in pencil are adequate. But pencil plotters are often lost in most discussions of plotting technology. They deserve attention because pencils have inherent advantages. For instance, pencils do not skip or dry out. They begin drawing as soon as they land on the drawing media. Most pencil plotters monitor pencil wear and switch units before the graphite is spent.

In contrast, pen plotters without monitoring systems continue plotting even when their ink supply is expended. Furthermore, even the best pens often require several inches of plotting before ink starts flowing.

Pencil cartridges are more economical than ink pens. Ink pens cost from $2 to $20. Graphite produces crisp, clean plots on most media and the lead costs $0.10 to $0.15 each.

Pencils let the plotter move at maximum acceleration and speed for the duration of the plot. Ink requires plotting at slower speeds and accelerations to avoid skipping. Thus, pencil plotters finish sooner.

Dense pencil plots reproduce as well as ink. And pencil plots on film are nearly indistinguishable from ink. And pencil is erasable on any media, so that minor changes and last-minute alterations are clean and quick.

Most machines can handle pens as well as pencils. This allows putting pencils and pens in the rack and switching between the two. Picking between a flatbed or roll-feed plotter is another consideration. Generally, flatbed machines plot on a wider range of media, from tracing paper to cardboard, and they can plot to its edge. Roll-feed plotters, on the other hand, can plot on longer media and can pull paper off a roll, thereby allowing them to work longer hours unattended.

To speed plots, most machines have vector-sort features. These examine a series of lines that need plotting and sort them so that the beginning of the next line is nearest the end of the last line.

specialized circuits has helped reduce the penalty of higher resolution.

Scanning methods are also important in display quality. With interlaced scanning, the electron beam strikes every other line on each refresh. With noninterlaced scanning, the entire screen is covered in one pass. Noninterlaced scanning can show motion with much less blurring, and reduces flicker associated with alternate-line refreshing.

The time needed to fill a terminal screen is called drawing speed and depends on both resolution and data-transmission rate. For example, a 640 × 480 screen with 8 bits for color control at 9,600 bits/sec takes about 5 min to fill. Advanced hardware techniques increase this speed, and more functions in the terminal reduce reliance on a host computer.

Raster terminals have excellent contrast for easy viewing in normal room lighting. Moreover, users may selectively erase part of an image without redrawing the entire screen because each pixel is controlled individually. This rapid updating also provides limited capability for depicting movement for screen animations.

The major advantage of raster terminals is that a range of colors or gray levels can be displayed simultaneously on the screen. Often, the terminal can also produce many more colors than it can display at any one time. The number of colors is controlled by video memory called bit planes. For example, a terminal with four bit-plane memory can display 2^4 or 16 color shades. Some high-end terminals have 24 bit planes and could show over 16 million colors if CRTs were not limited to 1 or 2 million pixels. To save memory, color palettes are used to provide a large selection of color shades, of which a smaller subset can be displayed at any time.

Unfortunately, raster displays are also subject to visible flicker, bright-to-dim oscillation that occurs when glowing phosphors begin to fade between sweeps of the electron beam. Blue phosphors, which fade more quickly than red or green phosphors, are especially prone to flicker. More than an inconvenience, flicker can cause serious problems for operators, including eye strain and headaches.

One of the most effective solutions to flicker is the use of long-persistence phosphors. These phosphors are specially treated to glow for a longer time than standard phosphors, substantially reducing the bright-to-dim oscillation. New long-persistence phosphors such as those made with zinc sulfide/silver have virtually eliminated

EVALUATING ELECTROSTATIC PLOTTERS

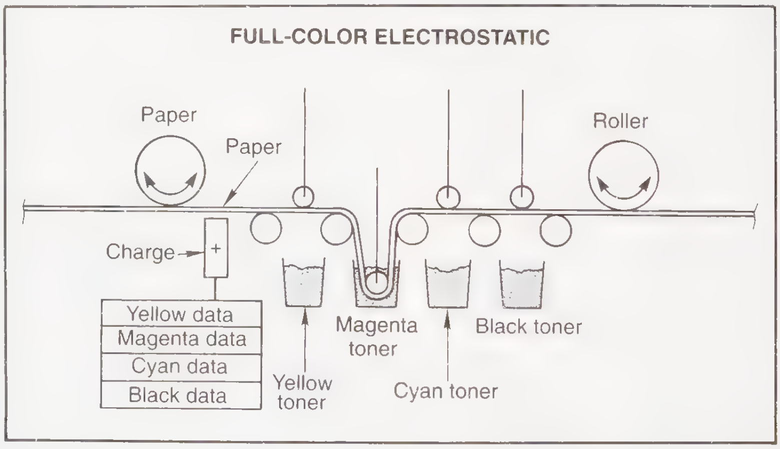
Electrostatic printer/plotters are replacing pen plotters in some applications. Though pen plotters are still more widely used, electrostatic plotters can produce drawings more quickly than pen plotters. Traditionally, they cost about 10 times as much as pen plotters, which still have better resolution. However, at least one manufacturer has a 400 points-per-inch (ppi) unit for about $6,000.

The need for fast color hardcopy is often the primary justification for electrostatic plotters. In a typical application, electrostatic plots let electronic designers differentiate circuits and logic paths or distinguish layers of a printed-circuit board. Mechanical engineers can use area-fill color and shading to make more realistic 3D images or to improve the display of finite-element analysis results, such as stress/strain distributions. Unlike pen plotters, electrostatic plotters can plot up to 1,024 colors.

Electrostatic and other raster plotters place a much greater burden on computer power and memory than pen plotters. Pen plotters directly use vector information to draw a design. Raster plotters must translate vector information into a series of dots in ordered scan lines.

The electrostatic plotting process itself consists of applying a programmed voltage to a densely spaced array of nibs in a stationary writing head. As paper passes over the printhead, the nibs create electrostatic dots on the paper, which is exposed to liquid toner to give a permanent image.

Monochrome plots are produced in a single pass, color plots usually in multiple passes. Both single-pass and multiple-pass color techniques use the three or four-color process, with a layer each of cyan, magenta, yellow, and (sometimes) black. Each layer or color separation requires as much data as one monochrome image.



Multiple-pass plotters write the color separations sequentially, but single-pass plotters need all color separation information simultaneously. This requires greater processing power and more data storage. But single-pass plotters are quicker than multiple-pass units and need only one registration rather than one for each color.

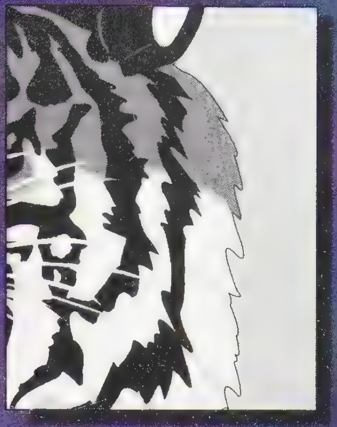
Dot-to-dot registration between color separations is important for good color. Consistency in registration and dot qualities are necessary for a consistent drawing. Dot size, especially, can affect drawing quality. Larger dots increase apparent density and contrast, but there is a trade-off with detail definition and resolution.

Raster plotters have resolutions expressed in points per linear inch because they plot dots an entire line at a time. Electrostatic plotter resolution is generally 200 to 400 ppi. Naturally, higher resolution costs more. But because dots are printed by the line, space between lines is also a major factor in print quality. A 400-ppi print might not look as good as a 200-ppi print with denser line spacing.

Higher resolution, like color, places greater demands on the processor and takes longer to print. However, many electrostatic plotters have additional processors.

All the benefits of a laser printer

A4 size



- DESKTOP CONVENIENCE
- RELIABILITY
- LOW COST
- SHARP, HIGH QUALITY OUTPUT
- FAST PRINTING SPEED
- PLAIN PAPER

A2 size

On a much larger scale.

At last. A personal output device that combines the best features of a desktop laser printer with the ability to produce large format drawings. It's called ProTracer — a 360 dpi desktop printer/plotter that produces A4, A3, as well as A2-size output.

ProTracer's speed and quiet operation come from the latest Canon inkjet technology and an Intel i960 processor. Drawings that take up to half an hour to print on a pen plotter take only five minutes on ProTracer!

And, unlike other large format devices, ProTracer isn't limited to plotting. Start with the ProTracer base unit that incorporates resident IBM ProPrinter and Epson LQ-1050 emulations, as well as an ADI plotter driver for AutoCAD users. Then, depending on your needs, choose from a variety of optional accessories including HP-GL® and PostScript® language emulation cards.

Optional Printer Accessories

- HP-GL emulation card
- PostScript language emulation card
- 2 MB memory upgrade
- 4 MB memory upgrade
- 8 MB memory upgrade
- Sheet feeder I (100 sheet)
- Sheet feeder II * (100 sheet)
- PacificTalk (AppleTalk interface module)

*Sheet feeder I is required for use

At Pacific Data Products, we're devoted to customer service. We offer a one year warranty and free lifetime technical support. Should you require a replacement unit while under warranty, one will be rushed to you immediately to minimize your downtime.

If you'd like to expand your printing and plotting capabilities, call:

Singapore • Pacific Technology tel: 65-271-1123, **Indonesia** • PT Harrisma tel: 62-21-549-0413, **Malaysia** • Mal-Pacific Technology tel: 60-3-248-9132, **Hong Kong** • Universal Electronics tel: 852-529-4433, **Taiwan** • Transcend Information tel: 886-2-767-2079.

PACIFIC DATA
PRODUCTS

Pacific Data Products, Inc., 9125 Rehco Road, San Diego, CA 92121, (619) 552-0880 Fax (619) 552-0889 ProTracer is a trademark of Pacific Data Products, Inc. PostScript is a registered trademark of Adobe Systems, Inc. Canon is a registered trademark of Canon, Inc. All other trade names referenced are the trademarks or registered trademarks of the respective manufacturer. Nozzle image courtesy of AutoDesk Inc. Tiger rendering, artist unknown; picture part of public domain. ProTracer uses the latest in high technology innovations including PeerlessPage™ the advanced Imaging Operating System from Peerless. EUROPEAN OFFICES: England Tel 0800 51 5511 Fax (44) 442 236540; France Tel 05 90 6509, Fax (33) 1 39 63 31 20 Germany Tel 0130 81 3685; Ireland Tel (353) 61 362609, Fax (353) 61 362608, Switzerland Tel (41) 22 341 26 50, Fax (41) 22 341 06 82. © 1992 Pacific Data Products, Inc

Circle 676

HIGH-RESOLUTION PC GRAPHICS

When it comes to CAD on PCs, two main gripes frequently crop up with respect to graphics. First, it can take several minutes to regenerate a complicated view after some operation such as a pan or zoom. Second, PC graphic resolution lags that of workstations. Super VGA found on high-end PCs is 1,024 × 768 at best, which is at the low end of Unix workstation resolution.

Graphics boards optimized for CAD applications solve such problems. Some systems can perform a zoom in 2 sec and provide a super VGA resolution or better.

These boards speed graphics operations by taking over functions such as rotations, translations, or enlargements of images. Special processors on the board recalculate the location, color and intensity of each picture element (pixel) of the screen. In addition, these processors generate video control and timing signals.

The boards also are equipped with large amounts of RAM, enough to hold an entire high-resolution screen of information. Some board makers employ video RAM (VRAM) to speed display refresh operations. VRAMs are dual ported with a parallel port for the CPU and graphics processor and a serial port to the display. However, VRAMs tend to be expensive and used only in high-end systems.

Some companies claim boards so equipped have zoom or pan speeds of about 2 sec. Typically, a board's display list memory is large enough (1M byte) to store about 200,000 CAD vectors. Most complex E-size drawings contain half this number of vectors. But there is a big difference between the size of a CAD drawing file and the size of the corresponding display list. A display list is typically about 40% smaller than the drawing file. This is because the display list contains only information about the location and types of lines in the drawing. The drawing file also contains data about whether lines in the drawing are on different layers, hooks for autodimensioning, and nongraphical information about objects. Typical nongraphical information might include a bill of materials.

However, sometimes a display list can be larger than the equivalent drawing file, as when text or graphics primitives are stored in ASCII characters. A display list needing more than 1M byte can be divided in two, with each piece saved as a separate file or displayed with less resolution.

Many high-resolution graphics boards will not work with software other than the specific CAD package for which they are designed. They simply can't be used with text-oriented programs such as Lotus 1-2-3 or high-level language programs.

The problem is that most high-resolution boards have neither the software drivers nor the hardware for such applications. And the high-resolution scan rates are incompatible with lower resolution equipment. For example, EGA boards generate a scan rate of 22 kHz, but many high-resolution boards operate near 50 kHz. The only way around the problem is to use two monitors and switch between them.

blue-based flicker.

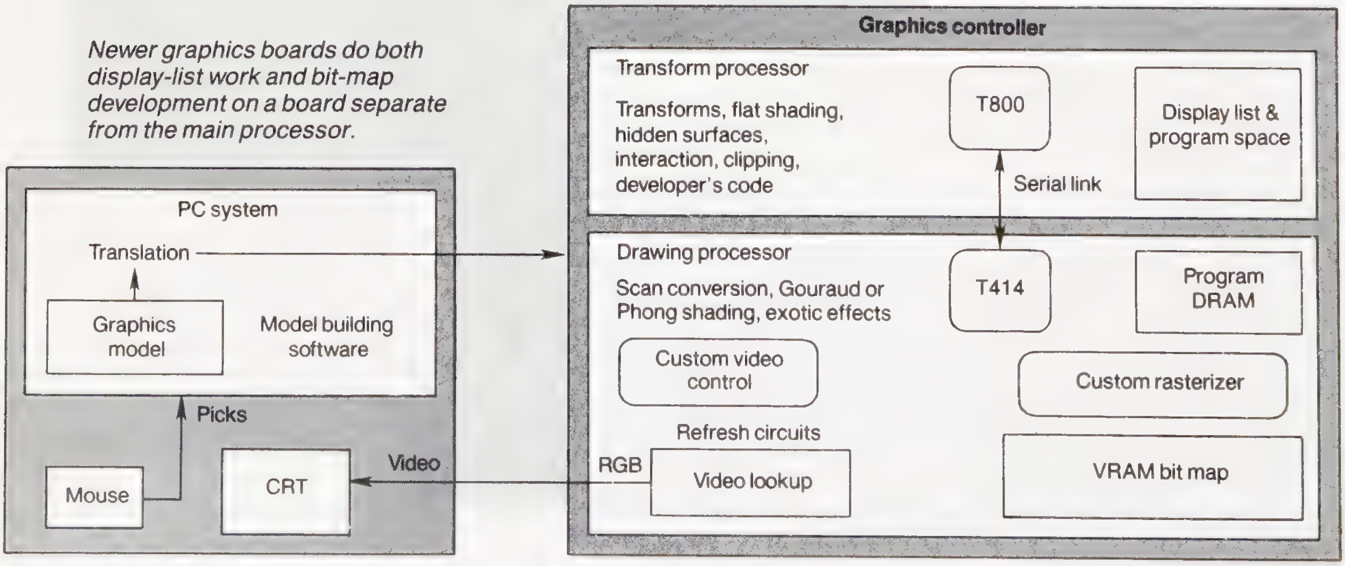
For high-speed presentation graphics or animation, however, the afterglow of long-persistence phosphors is unacceptable. For these applications, flicker can be eliminated by increasing the frequency at which the electron beams refresh the phosphors. Refresh frequencies in these monitors are usually 50 to 60 Hz or even higher.

Beyond flicker, other display quality issues have yet to be completely resolved. Because raster tubes are made of glass, they are highly reflective and subject to glare. Glare can be reduced by special coatings or tinted faceplates bonded to the tubes. Etched faceplates low in transmissiveness can cut glare and improve contrast.

In **vector refresh** (also called stroke-writing, random-scan, or calligraphic systems), the electron/writing beam is deflected to directly trace image lines on a screen in a continuous sweep similar to the approach used in oscilloscopes. After the beam has generated the complete image, it repeatedly retraces or refreshes the picture before the phosphor fades. The displayed image is stored in memory and is constantly refreshed, generally under control of a special-purpose display processor.

Vector-refresh terminals have high brightness, and resolution is excellent because image lines are produced by a continuous sweep of the writing beam instead of a dot matrix. Some of these terminals offer color, but not as many as raster techniques. Selective erasing features are also available. The major benefit of vector-refresh terminals has been the ability to display motion on the screen, allowing images to be magnified, rotated, or translated as the user watches.

Newer graphics boards do both display-list work and bit-map development on a board separate from the main processor.



The major disadvantage of vector-refresh devices is that the display starts to flicker if a substantial amount of data is on the screen. For most graphics applications, the refresh cycle (time required to trace out all lines in an entire image) is fast enough to make the image appear to have constant intensity. Complex images with more than 4,000 vector-inches of graphics may reduce refresh rate to below 30 Hz, which appears to the human eye as flicker. Another limitation of vector-refresh terminals is that additional hardware and memory required make such systems one of the most expensive types. ■

MASS STORAGE PERIPHERALS

The most commonly used mass-storage devices for backing up CAD data are magnetic-tape cartridges. Also used are removable hard disks and optical disks. Two newer types of storage are digital-audio tape and high-density floppy disks.

Today, magnetic-tape cartridges can store up to 2G bytes of data. They often are used to do daily, incremental backup of files, or to archive whole hard disks. However, it takes time to find a specific piece of data on a reel of tape, so they cannot be utilized in applications where access time is important.

Data files are written to magnetic tape in a serpentine pattern, on various tracks. Most tapes are divided into 20 or so tracks, although some high-density tapes contain more than 40 tracks. Files are listed in a directory as they are written to the tracks. The drive accesses data by querying the directory, which lists the track or tracks on which data are written. Embedded servos in more-expensive magnetic-tape storage devices allow accurate positioning of the head on tapes with many tracks.

Removable hard-disk drives and optical disks are appropriate when fast, random access to data is required. However, both removable hard-disk drives and optical discs are relatively expensive. Optical-disc costs vary depending on the physical size of the platter and the number of laser diodes in the disc drive. Hard disks are less expensive, but generally used in different circumstances. Removable hard disks are often used to backup individual users, while optical discs can be used for archiving.

continued on page 830

UNDERSTANDING MONITOR SPECS

There is a cost trade-off between color and resolution in monitors. High-resolution color monitors cost much more than monochrome units with similar resolution. Experts advocate higher resolution and fewer colors for most engineering uses. Noteworthy exceptions are applications such as multilayer PCB design or solid modeling.

Resolution is another consideration. Vendors often describe the resolution of their products in terms of pixels per screen. For instance, if resolution is 1,024 × 748, 1,024 is the number of pixels per horizontal raster line, while 728 is the number of lines. A problem with describing resolution this way is that it does not take screen size into account. A 1,024 × 728 image on a 19-in. screen is less clear than the same image on a 13-in. screen.

A more accurate description, according to some experts, may be dots per inch (dpi). Dpi is the density of pixels on the screen based on its height and width. Vertical and horizontal pixel density usually is equal in a display, so dpi is specified as a single number. Most PC screens have dpi resolutions of between 40 and 72, although some high-resolution monochrome monitors have resolutions as high as 300 dpi.

Monitor literature will also use the terms scan frequency, video data rate, and monitor bandwidth. These factors acting together also affect resolution. The horizontal and vertical scan frequencies determine the number of horizontal raster lines per screen. Video data rate is the speed, in megahertz, at which the graphics controller provides pixels. It determines the number of pixels per scan line. Monitor bandwidth describes the rate, in megahertz, at which the video amplifier can accept pixels to produce the required resolution.

Flicker is a subtle flashing of the computer image that occurs when the screen phosphors are not rewritten fast enough, so that the images fades considerably before it is refreshed. Flicker can be distracting to the terminal operator. Refresh rate and whether screens are interlaced or noninterlaced affect whether the operator sees flicker.

On interlaced displays, only half the raster lines are refreshed every time the screen is updated. Noninterlaced displays refresh all raster lines every update. Flicker may be more pronounced when static images display on interlaced screens. Most monitors today are noninterlaced, although some multiscan monitors provide interlaced displays in their high-resolution modes. Multiscan monitors have adjustable scan frequencies.

On noninterlaced displays larger than 13 in., a refresh rate greater than the typical 60-Hz rate may be needed to avoid flicker. Larger computer screens place more image in peripheral vision, which is sensitive to flicker. Ergonometric studies show that most users can detect flicker when using a 19-in. screen refreshed at 60 Hz. When refresh rate rises to 70 Hz, however, less than 10% of users notice flicker on the same size screen.

Other, less-significant measures of image sharpness are dot pitch and phosphor type. Whether a phosphor is long or short persistence refers to how long it is. Long-persistence phosphors, which can reduce flicker in interlaced displays, may leave an afterimage.

Dot pitch is the distance between the triads that make up each pixel in a color display. Color triads are groupings of red, green, and blue phosphor dots that are turned on and off to form the colors in a display. According to experts, the best dot pitch for a high-resolution screen is 0.21 mm, while dot pitch greater than 0.36 mm is considered inferior.

STRUCTURAL DESIGN
ON YOUR PC!!!

Integrated Solution for $995.00
- Frame and Truss Structures
- Finite Element Solutions
- 600 Members & 600 Joints
- Less Than 30 Seconds
- Material Properties Selector
- AISC Data Base
- Properties Calculator

BEAM DESIGN

Simplicity & Speed at $495.00
- Any Beam and Load
- Under 28 Seconds!
- Deflection Diagrams

Call Toll-Free
800-321-7003
In Ohio (216)696-7000

Penton Education Division
1100 Superior Avenue
Cleveland, Ohio 44114

Engineering Software Company

continued from page 829

Uses of removable storage devices

Device	Sony-HP DAT	Hitachi DAT	Removable winchester	WORM	Magneto optic	CD-ROM	Current magnetic tape	Future magnetic tape	Advanced hi-density floppy
Archive data	X	X		X	X		X	X	X
Interchange network					X		X	X	X
Back-up software	X	X		X	X		X	X	
Distribution user					X	X	X	X	X
Back-up			X			X	X	X	X

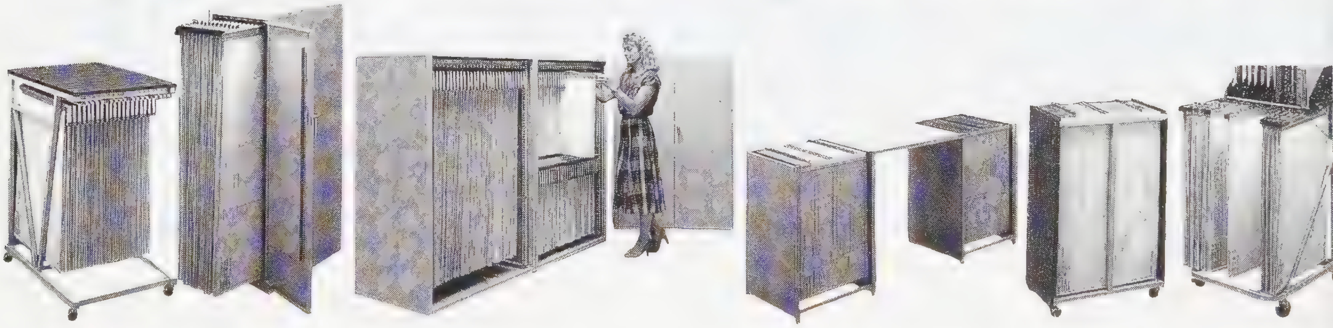
Today, optical discs are available as either read-only or write-once read many (Worm) devices. However, magneto-optic, or erasable, discs soon may be available. Maximum capacity of optical discs varies with platter size, and can range from about 10M bytes to several gigabytes. On the other hand, removable hard disks are limited to about 20M bytes of data, although 40M-byte devices may soon be available.

Also, new high-density floppy disks may become an alternative for random-access storage. They may prove to be an alternative to removable hard disks, or may be used in portable computers.

Since each form of backup media has its own advantages and disadvantages, users should ask the following questions before committing to a storage scheme.

- What is the capacity of the media? Some applications, such as incremental backup, require devices that can store gigabytes.
- What is the throughput of the system? Throughputs in excess of 5M bytes per minute are considered high enough for applications such as large data transfers.
- How much time is required to access data? If a user requires random access to data, hard disk, floppies, or optical discs can be used.
- What is the cost? Expensive systems such as optical discs would be impractical for applications like daily backup.

GOT A PROBLEM?
HAVING TROUBLE FINDING THE ROOM TO STORE ALL YOUR REPROGRAPHIC PRINTS?



Look no further. For over 35 years, engineers and draftsmen alike have chosen the quality and dependability of Plan Hold products for cost-effective filing of blueprints and other large documents.

WE'RE STILL THE LEADER!

Put our experience to work and let our experts help you select the file that's right for you. Send for our free literature and discover that your problems weren't as big as you thought.

Plan Hold

17421 VON KARMAN AVENUE IRVINE, CALIFORNIA 92714-6293 • 1-714-660-0400 • FAX: 1-714-474-8076

Circle 575

CAD/CAM

Write this number on the Reader Service Card to receive information from all advertisers making the listed products.

COMPUTERS FOR CAD/CAM

1409 Memory boards
1410 Minicomputers
1411 Turnkey systems, analysis
1412 Turnkey systems, machine vision
1413 Workstations

DESIGN, MODELING & ANALYSIS

1414 Analysis software
1415 Drafting software
1416 General software
1417 Modeling software
1418 Other software
1419 PC software

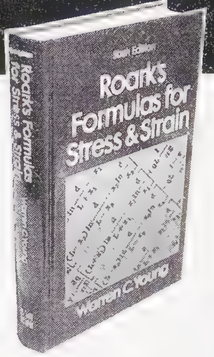
PERIPHERAL HARDWARE

1420 Digitizers
1421 Displays, color
1422 Displays, LCD
1423 Plotters

ENGINEERING TEST EQUIPMENT

1424 Calibrators
1425 Instrumentation equipment
1426 Vibration analyzers

STRESS ANALYSIS ON YOUR PC USING ROARK & YOUNG'S BOOK "FORMULAS FOR STRESS & STRAIN"



Since 1938 Roark's *Formulas for Stress & Strain* has maintained its position as one of the most widely used engineering reference works in the world. Now 37 tables, over 1400 cases and more than 5000 formulas from the new 6th Edition of this book are combined for the first time with the power of TK Solver software

The program covers the entire 6th Edition of the book • Provides stress and strain solutions for beams, plates, columns, and pressure vessels • Handles superposition of loads • A set of unit conversions and an expandable materials library are included • Program menuing system helps you select the particular chapter, table and case from the book • Results include plots of cross-section (to scale) bending moment, shear, stress, slope and deflection • Outputs to screen, printer or plotter.

Most importantly — you can solve problems forward or backward. For example: if the calculated deflection of a plate is too great, specify the maximum deflection you can tolerate. Then let the dimension of plate thickness become the unknown, and solve again. This backsolving feature is a designer's dream.

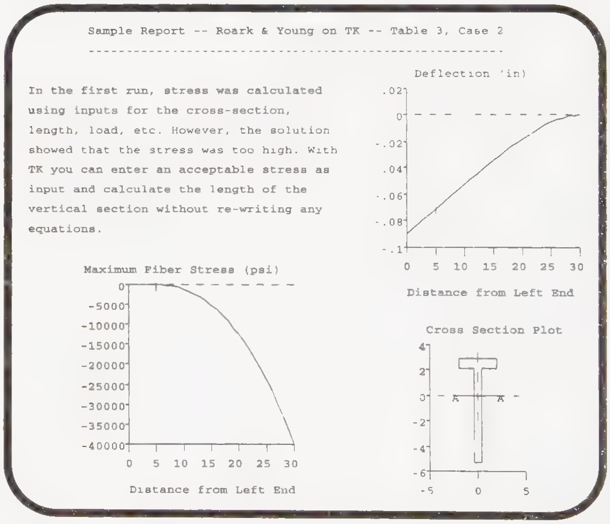
ROARK & YOUNG ON TK $1190

(For the IBM PC family or compatibles, 286 PC/MS Dos 3.2 or greater, 1 meg RAM)

(NOTE! The $1190 price includes TK Solver software (below) and a copy of the new 6th Edition.)

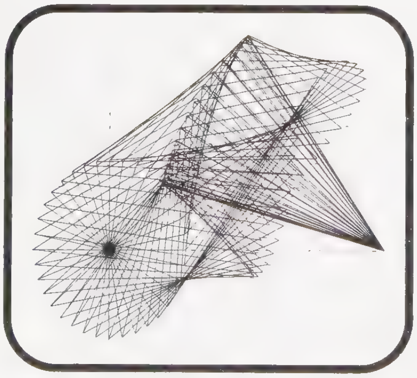
TK Solver 2.0 software . . . $595

Solve dozens of linear, non-linear or differential equations simultaneously • backsolving lets you do "What-if" analysis • iterative solving • list solving • automatic plotting • automatic unit conversion • differentiation and integration • over 100 built-in functions and library routines • math co-processor support • presentation view lets you generate WYSIWYG reports • MathLook feature displays equations in near mathematical notation • keystroke macros with samples • link to many symbolic math packages.



Sample Report -- Roark & Young on TK -- Table 3, Case 2

In the first run, stress was calculated using inputs for the cross-section, length, load, etc. However, the solution showed that the stress was too high. With TK you can enter an acceptable stress as input and calculate the length of the vertical section without re-writing any equations.



SPECIAL OFFER!

If you order Roark & Young on TK, or TK Solver before July 31, 1992 you'll receive FREE a copy of Graphics 2000 Software — a $395 value!

When two-dimensional plots aren't enough, you can use Graphics 2000 software for precision 3D graphics and display. Visualize and present data, rotate about any axis, add light sources, modify numeric values or manipulate your results graphically. Smooth links with TK let you update your entire problem and display the results immediately in high-resolution 3D.

SATISFACTION GUARANTEED

Use these programs on your PC. If they don't perform as described, just return the packages within 30 days for full credit or refund.

PENTON EDUCATION DIVISION
1100 Superior Avenue
Cleveland, Ohio 44114

Toll-free 800-321-7003 (in Ohio 216/696-7000)
FAX 216-696-4369

MATERIALS

Advertisers

Alfco 913
Alloy Technology International, Inc. 953,974
Ames Rubber Corporation 906
Aremco Products, Incorporated 975
Arlon 953
BASF Corporation 849,861
Carpenter Technology,
  Carpenter Steel Division 937-940
Courtaulds Performance Films 849
Da/Pro Rubber, Inc. 907
Diamonite 975
Du Pont, E.I. de Nemours, Inc.,
  Polymers 867,869,871
Dynacast Incorporated 918
E.A.R. Specialty Composites
  Corporation 965-968
Enthone - OMI, Inc. 976
Fishercast Div. of Fisher
  Gauge Limited 925-928

A
ABS/SAN 836
Acetal 837
Acrylic 843
Alkyd 844
Alloy steel 946
Allyl 845
Aluminum 911
Amino 846
Aramid fiber 886,899
B
Beryllium 914
C
Carbon 958
Carbon fibers 885,890,899
Carbon steel 936
Cast iron 942
Cellulosics 848
Ceramic-matrix composites 896
Chlorotrifluoroethylene (CTFE) 855
Copper 915
E
Engineering ceramics 958
Engineering films 850
Epoxy 851,890
Ethylene tetrafluoro ethylene (ETFE) 854
Ethylene-chlorotrifluoro ethylene
  (ECTFE) 857
Ethylene-vinyl acetate 873
F
Ferrous metallurgy 934
Ferrous P/M 956
Fiber-reinforced polyester (FRP) 864
Fibers 898
Films 850
Fluorinated ethylene propylene (FEP) 854
Fluoroplastics 854
G
Glass 964
Glass fibers 884,890,898
H
HSLA steel 954
I
Ionomer 874
Iron-based superalloys 956
L
Laminated plastics 891
Lead 916
Liquid-crystal polymers 857
M
Magnesium 917
Metal coatings 977
Metal-matrix composites 892
N
Nickel 919
Noise-control materials 969
Nylon 858
O
Optimizing materials 883

Plastics

Composites

Elastomers & rubbers

Nonferrous metals

Ferrous metals

Additional engineering materials

Coatings, platings, & finishes

GE Plastics 847
General Magnaplate 980
Gibbs Die Casting Aluminum Corp. 921
Harrington & King Perforating Co., Inc. 913
Hoechst Celanese Corporation 852-853
Hoechst Celanese Corporation,
  PBI Performance Parts 839-842
Hynes 943
ITW Philadelphia Resins 861
Intech 861
Kleerdex Company 849
Machine Design Research 887-888
Minor Rubber Company, Inc. 909
Nimet Industries, Inc. 980
Porex Technologies, Inc. 868
Rogers Corporation 959-963
Sandusky International 2
Sorbothane, Inc. 971
Stahl Specialty Company 922
Trim-Lok, Inc. 910
UCAR Carbon Company, Inc. 973
United Process, Inc. 974

P
Perfluoroalkoxy (PFA) 854
Phenolic 859,890
Polyamide 858
Polyamide-imide 860
Polybenzimidazole (PBI) 862
Polybutylene 874
Polybutylene terephthalate (PBT) 865
Polycarbonate 863
Polydicyclopentadiene (PDCPD) 874
Polyester 864,890
Polyetheretherketone (PEEK) 869
Polyetherimide 866
Polyetherketone (PEK) 869
Polyetherketoneketone (PEKK) 869
Polyethersulfone (PES) 881
Polyethylene 870
Polyethylene terephthalate (PET) 865
Polyimide 868
Polyketones 869
Polymer coatings 977
Polymethylpentene 874
Polyolefins 870
Polyphenylene ether 874
Polyphenylene sulfide 875
Polypropylene 873
Polystyrene 876
Polysulfone 881
Polytetrafluoroethylene (PTFE) 854,889
Polyurethane 878
Polyvinyl chloride 879
Polyvinyl fluoride (PVF) 854
Polyvinylidene fluoride (PVDF) 856
Precious metals 922
R
Refractory hard metals 972
Refractory metals 923
S
Silicone 903
Stainless steel 948
Steels for strength 936
Structural foam 880
Sulfone polymers 881
Styrenic-maleic-anhydride (SMA) 877
T
Tetrafluoroethylene (TFE) 854
Thermoplastic composites 884
Thermoplastic elastomers 906
Thermoplastics 835
Thermoset composites 890
Thermoset rubber 900
Thermosets 836
Tin 929
Titanium 930
Tool steel 952
Z
Zinc 931
Zirconium 933

Plastics

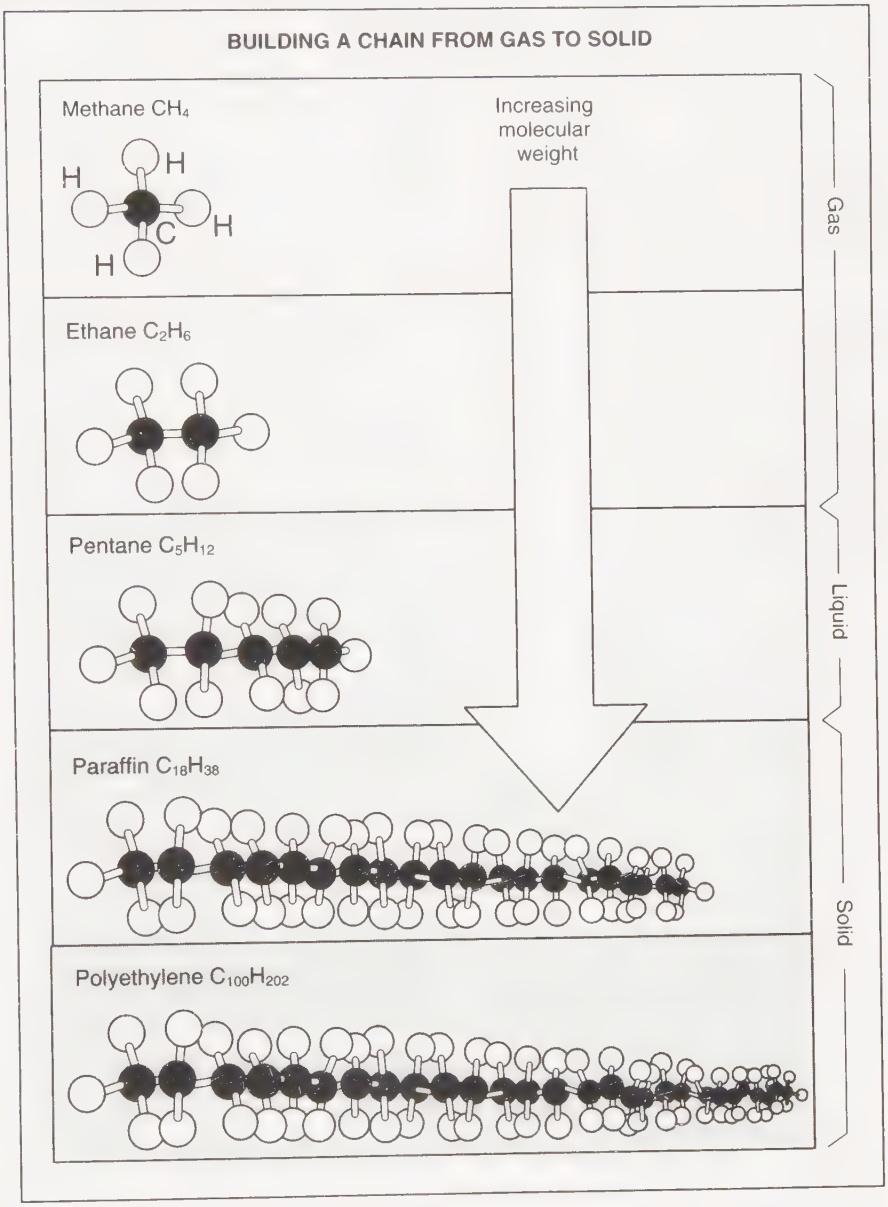
Polymers continue to advance into engineering applications that range from automotive and aerospace to medical and electrical.

Plastics are synthetic materials made from chemical raw materials called monomers. A monomer (one chemical unit) such as ethylene is reacted with other monomer molecules into long chains of repeating ethylene units, forming the polymer polyethylene. In a similar manner, polystyrene is formed from styrene monomer; polypropylene from propylene monomer; and other thermoplastic polymers from their respective monomers.

Plastics begin as a gas (monomer), approach the liquid state for forming, and end up as a solid in their finished form. They can be formed by heat, pressure, or a combination of the two. Adding reinforcements to plastics creates a different class of materials known as composites.

Polymers consist of atoms of carbon in combination with other elements. Polymer chemists use only eight of the more than 100 known elements to create thousands of different plastics. These eight elements are carbon, hydrogen, nitrogen, oxygen, fluorine, silicon, sulfur, and chlorine.

Combining these atoms in various ways produces extremely large, complex molecules. Each atom has a limited capacity (energy bonds) for joining to other atoms, and every atom within a molecule must have all of its energy bonds satisfied if the compound is to be stable. Hydrogen, for example, can bond to only one other atom, while carbon or silicon must attach to four other atoms to satisfy its four energy bonds. Thus, H-H and H-F are stable molecules, but C-H and Si-Cl are not.


BUILDING A CHAIN FROM GAS TO SOLID

Thermoplastics

Groups of stable, organic compounds, called monomers, are used to make plastics. Starting with billions of molecules of monomer in a reactor, heat and pressure are applied in the presence of catalysts, causing one of the monomer double bonds to rearrange into two "half bonds," one at each end. These half bonds combine with half bonds of other rearranged monomer molecules, forming stable "whole bonds" between them. As each monomer joins with others, the chain length grows until it meets a stray hydrogen, which combines with the reactive end, stopping chain growth at that point.

During the polymerization reaction, millions of separate polymer chains grow in length simultaneously, until all of the monomer is exhausted. By adding predetermined amounts of hydrogen (or other chain-stoppers), chemists can produce polymers having a fairly consistent average chain length. Chain length (molecular weight) is important because it determines many properties of a plastic, and it also affects its processing characteristics. The major effects of increasing chain length are increased toughness, creep resistance, stress-crack resistance, melt temperature, melt viscosity, and processing difficulty.

All polymer molecules cannot be manufactured to an exact, specified length, however, so each batch will have an average molecular-weight distribution. There can be either a broad or a narrow spread between molecular weights of the largest and smallest molecules, and the polymer still could have the same average. A narrow distribution provides more uniform properties; a broad distribution makes a plastic easier to process.

After polymerization is completed, the finished polymer chains resemble long, intertwined bundles of spaghetti, with no physical connections between chains. Such a polymer is called a thermoplastic (heat-moldable) polymer.

Thermosets

Thermoset plastics are made quite differently from thermoplastics. Polymerization (curing) of thermoset plastics is done in two stages, partly by the material supplier and partly by the molder. As illustrated in Fig. 4, phenolic (a typical thermoset plastic) is first partially polymerized by reacting phenol with formaldehyde under heat and pressure. The reaction is stopped at the point where mostly linear chains have been formed. The linear chains still contain unreacted portions, which are capable of flowing under heat and pressure.

The final stage of polymerization is completed in the molding press, where the partially reacted phenolic is liquefied under pressure, producing a crosslinking reaction between molecular chains. Unlike a thermoplastic monomer, which has only two reactive ends for linear chain growth, a thermoset monomer must have three or more reactive ends so that its molecular chains crosslink in three dimensions. Rigid thermosets have short chains with many crosslinks; flexible thermosets have longer chains with fewer crosslinks.

After it has been molded, a thermoset plastic has virtually all of its molecules interconnected with strong, permanent, physical bonds, which are not heat reversible. Theoretically, the entire molded thermoset part could be a single giant molecule. In a sense, curing a thermoset is like cooking an egg. Once it is cooked, reheating does not cause remelting, so it cannot be remolded. But if a thermoset is heated too much or too long, the chains break and properties are degraded.

Phenolic, urea, and melamine thermoset plastics are polymerized by a "condensation" reaction, wherein a by-product (water, for example) is created during the reaction in the mold. Such volatile by-products cause dimensional instability and low part strength unless they are removed during molding.

Other thermoset plastics, such as epoxy and polyester, cure by an "addition" reaction, resulting in no volatile by-products and fewer molding problems. Most addition-cured thermoset plastics are liquid at room temperature; the two ingredients can simply be mixed and poured into molds where they crosslink (cure) at room temperature into permanent form — much like casting concrete. Molds are often heated, however, to speed the curing process.

In general, thermoset plastics, because of their tightly crosslinked structure, resist higher temperatures and provide greater dimensional stability than do most thermoplastics. Examples of thermoset plastic products include glass-reinforced-polyester boat hulls and circuit-breaker components, epoxy printed-circuit boards, and melamine dinnerware.

ABS/SAN

Consisting of particles of a rubberlike toughener suspended in a continuous phase of styrene-acrylonitrile (SAN) copolymer, ABS resins are hard, rigid, and tough, even at low temperatures. Various grades of these amorphous, medium-priced thermoplastics are available offering different levels of impact strength, heat resistance, flame retardance, and platability. Principal producers of ABS resins in the U.S. are GE Plastics (Cycolac), Dow Chemical Co. (Magnum), and Monsanto Chemical Co. (Lustran).

Most natural ABS resins are translucent to opaque, but they are also produced in transparent grades, and they can be pigmented to almost any color. Grades are available for injection molding, extrusion, blow molding, foam molding, and thermoforming. Molding and extrusion grades provide surface finishes ranging from satin to high gloss. Some ABS grades are designed specifically for electroplating. Their molecular structure is such that the plating process is rapid, easily controlled, and economical.

Compounding of some ABS grades with other resins produce special properties. For example, ABS is alloyed with polycarbonate to provide a better balance of heat resistance and impact properties at an intermediate cost. Deflection temperature is improved by the polycarbonate; molding ease, by the ABS. Other ABS resins are used to modify rigid PVC for use in pipe, sheeting, and molded parts. Reinforced grades containing glass fibers, to 40%, are also available.

Related to ABS is SAN, a copolymer of styrene and acrylonitrile (no butadiene) that is hard, rigid, transparent, and characterized by excellent chemical resistance, dimensional stability, and ease of processing. SAN resins are usually processed by injection molding, but extrusion, injection-blow molding, and compression molding are also used. They can also be thermoformed, provided that no postmold trimming is necessary. (Because the material is not toughened, thermoformed shapes may crack during conventional trimming operations.)

Properties: ABS plastics offer a good balance of tensile strength, impact and abrasion resistance, dimensional stability, surface hardness, rigidity, heat resistance, low-temperature properties, chemical resistance, and electrical characteristics. These materials yield plastically at high stresses, so ultimate elongation is seldom significant in design; a part usually can be bent beyond its elastic limit without breaking, although it does stress-whiten. While not generally considered flexible, ABS parts have enough spring to accommodate snap-fit assembly requirements.

Impact properties of ABS are exceptionally good at room temperature and, with special grades, at temperatures as low as −40°F. Because of its plastic yield at high strain rates, impact failure of ABS is ductile rather than brittle. Also, the skin effect which, in other thermoplastics, accounts for a lower impact resistance in thick sections than in thin ones, is not pronounced in ABS materials. A long-term tensile design stress of 1,000 to 1,500 psi (at 73°F) is recommended for most grades.

General-purpose ABS grades may be adequate for some outdoor applications, but prolonged exposure to sunlight causes color change and reduces surface gloss, impact strength, and ductility. Less affected are tensile strength, flexural strength, hardness, and elastic modulus. Pigmenting the resins black, laminating with opaque acrylic sheet, and applying certain coating systems provide weathering resistance. For maximum color and gloss retention, a compatible coating of opaque, weather-resistant polyurethane can be used on molded parts. For weatherable sheet applications, ABS resins can be coextruded with a compatible weather-resistant polymer on the outside surface.

ABS resins are stable in warm environments and can be decorated with durable coatings that require baking at temperatures to 160°F for 30 to 60 min. Heat-resistant grades can be used for short periods at temperatures to 230°F in light load applications. Low moisture absorption contributes to the dimensional stability of molded ABS parts.

Molded ABS parts are almost completely unaffected by water, salts, most inorganic acids, food acids, and alkalies, but much depends on time, temperature, and especially stress level. FDA acceptance depends to some extent on the pigmentation system used. The resins are soluble in esters and ketones, and they soften or swell in some chlorinated hydrocarbons, aromatics, and aldehydes.

Properties of SAN resins are controlled primarily through acrylonitrile content and by adjusting the molecular weight of the copolymer. Increasing both improves physical properties, at a slight penalty in processing ease. Properties of the resins can also be enhanced by controlling orientation during molding. Tensile and impact strength, barrier properties, and solvent resistance are improved by this control.

Special grades of SAN are available with improved UV stability, vapor-barrier characteristics, and weatherability. The barrier resins — designed for the blown-bottle market — are also tougher and have greater solvent resistance than the standard grades.

Applications: Molded ABS products are used in both protective and decorative applications. Examples include safety helmets, camper tops, automotive instrument panels, and other interior components, pipe fittings, home-security devices and housings for small appliances, communications equipment, and business machines. Chrome-plated ABS has replaced die-cast metals in plumbing hardware and automobile grilles, wheel covers, and mirror housings.

Typical products vacuum-formed from extruded ABS sheet are refrigerator liners, luggage shells, tote trays, mower shrouds, boat hulls, and large components for recreational vehicles. Extruded shapes include weather seals, glass beading, refrigerator breaker strips, conduit, and pipe for drain-waste-vent (DWV) systems. Pipe and fittings comprise one of the largest single application areas for ABS.

Typical applications for molded SAN copolymers include instrument lenses, vacuum-cleaner and humidifier parts, medical syringes, battery cases, refrigerator compartments, food-mixer bowls, computer reels, chair shells, and dishwasher-safe houseware products. Because of their compatibility with many higher-priced resins, SAN resins are also used as color-concentrate carriers for some engineering resins.

Acetal

Acetal resins are highly crystalline plastics based on formaldehyde polymerization technology. These engineering resins are strong, rigid, and have good moisture, heat, and solvent resistance. Acetals produced in the U.S. include homopolymers by Du Pont Co. (Delrin) and copolymers by Celanese Engineering Plastics Div., Hoechst Celanese Corp. (Celcon).

Melting points of the homopolymers are higher, and they are harder, have higher resistance to fatigue, are more rigid, and have higher tensile and flexural strength with generally lower elongation. Some high-molecular-weight homopolymer grades are extremely tough and have higher elongation than the copolymers. Homopolymer grades are available that are modified for improved hydrolysis resistance to 180°F, similar to copolymer materials.

The copolymers remain stable in long-term, high-temperature service and offer exceptional resistance to the effects of immersion in water at high temperatures. Neither type resists strong acids, and the copolymer is virtually unaffected by strong bases. Both types are available in a wide range of melt-flow grades.

The copolymers process easier and faster than the conventional homopolymer grades. However, with the introduction in 1987 of Delrin II homopolymer resins, Du Pont claims to have eliminated that difference. The improve moldability is attributed to the use of a new thermal stabilizer, which gives Delrin II the thermal stability of copolymers while retaining the higher properties of the homopolymer.

Both the homopolymers and copolymers are available in several unmodified and glass-fiber-reinforced injection-molding grades. Both are available in PTFE or silicone-filled

ABS and SAN

ASTM or UL test	Property	- STANDARD ABS GRADES -			SPECIAL-PURPOSE ABS GRADES					
		High impact	Superhigh impact	Medium impact	High heat	Flame retardant	Clear	Expandable	Plating	SAN grades
	PHYSICAL									
D792	**Specific gravity**	1.01-1.05	1.02-1.05	1.04-1.06	1.04-1.06	1.19-1.22	1.05	0.55-0.85	1.05-1.07	1.07-1.08
D792	**Specific volume** (in.^{3}/lb)	27	27	28	28	—	26	—	26	26
	MECHANICAL									
D638	**Tensile strength** (psi)	6,000	5,000-6,300	6,000-7,500	6,000-7,500	5,500-10,000	5,800-6,300	3,000-4,000	5,500-6,600	9,000-12,000
D638	**Elongation** (%)	5-20	5-70	5-25	3-20	5-25	25-75	—	—	1-4
D638	**Tensile modulus** (10^5 psi)	3.3	2.0-3.4	3.6-3.8	3.0-4.0	3.2-3.7	3.0-3.3	1.0-2.5	3-3.8	4.5-5.6
D790	**Flexural strength** (psi)	10,500	6,000-11,500	11,500	10,000-13,000	9,000-12,250	10,500	3,000-8,000	8,700-11,500	14,000-17,000
D790	**Flexural modulus** (10^5 psi)	3.4	2.0-3.5	3.6-4.0	3.1-4.0	3.0-3.4	3.4-3.9	1.4-2.8	3.0-3.8	5.5
D256	**Impact strength,** Izod (ft-lb/in. of notch)	6.5	7.0-8.0	4.0-5.5	2.3-6.0	4.0-13.0	2.5-4.0	—	5.0-7.0	0.35-0.50
D785	**Hardness,** Rockwell R	103	69-105	107	111	90-117	100-105	60-70*	103-109	M85
	THERMAL									
D696	**Coef of thermal expansion** (10^{-5} in./in.-°F)	5.3	5.6	4.6	3.9-5.1	3.7-4.6	4.6	4.9	4.7-5.3	3.0
D648	**Deflection temperature** † *(°F)									
	At 264 psi	188	192	184	220-240	180-220	168	160	189	210
	At 66 psi	203	208	201	230-245	198-238	180-185	185	214	—
UL 94	**Flammability rating**	HB	HB	HB	HB	V-0 to V-1§	HB	HB-V-0	HB	HB
	ELECTRICAL									
D149	**Dielectric strength** (V/mil) Short time, 1/8-in. thk	400	350-500	350-500	350-500	400+	400	—	—	—
D495	**Arc resistance** (s)	89	50-85	50-85	50-85	20-60	120-130	—	—	—

*Density has a marked effect. †Unannealed. §0.060-in. thick samples.

grades, and the homopolymer is available in chemically lubricated low-friction formulations. A blow-molding grade (actually, a terpolymer) of Celcon is also produced, and special, high-productivity molding grades of Delrin are available. Several grades of both types comply with Food and Drug Administration regulations for repeated contact with food at temperatures to 250°F. The National Sanitation Foundation has approved several homopolymer and copolymer resins for use in potable water to 180°F.

The acetals are also available in extruded rod and slab form for machined parts. These materials are readily machined with standard brass-cutting tools. Property data listed in the table apply to the general-purpose injection-molding and extrusion grade of Delrin 500 and to Celcon M90.

Acetals

ASTM or UL test	Property	Copolymer	Homopolymer
	PHYSICAL		
D792	**Specific gravity**	1.41	1.42
D792	**Specific volume** (in.^{3}/lb)	19.7	19.5
D570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.22	0.25
	MECHANICAL		
D638	***Tensile strength** (psi)		
	At 73°F	8,800	10,000
	At 160°F	5,000	6,900
D638	***Elongation** (%)	60	40
D638	***Tensile modulus** (10^5 psi)	4.1	5.2
D790	**Flexural strength** (psi)	13,000	14,100
D790	**Flexural modulus** (10^5 psi)		
	At 73°F	3.75	4.10
	At 160°F	1.80	2.30
D256	**Impact strength**		
	Izod (ft-lb/in.)		
	Notched	1.3	1.4
	Unnotched	20	24
D671	**Fatigue endurance limit,** 10^7 cycles (psi)	3,300	4,300
D785	**Hardness,** Rockwell M	80	94
	THERMAL		
C177	**Thermal conductivity**		
	(10^{-4} cal-cm/sec-cm^2-°C)	5.5	8.9
	(Btu-in./hr-ft^2-°F)	1.6	2.6
D696	**Coef of thermal expansion** −40 to +185°C (10^{-5} in./in.-°C)	8.5	10.0
D648	**Deflection temp** (°F)		
	At 264 psi	230	277
	At 66 psi	316	342
UL 94	**Flammability rating**	HB	HB
	ELECTRICAL		
D149	**Dielectric strength**		
	Short time (V/mil)		
	5 mils	2,100	3,000
	20 mils	—	2,000
	90 mils	500	500
D150	**Dielectric constant**		
	At 1 kHz	3.7	3.7
	At 1 MHz	3.7	3.7
D150	**Dissipation factor**		
	At 1 kHz	0.001	0.001
	At 1 MHz	0.006	0.005
D257	**Volume resistivity** (ohm-cm)		
	At 73°F, 50% RH	10^{14}	10^{15}
D495	**Arc resistance** (s) 120 mils	240 (burns)	220 (burns, no tracking)
	FRICTIONAL		
—	**Coefficient of friction**		
	Self	0.35	0.3
	Against steel	0.15	0.15

* At 0.2 in./min loading rate.

Acetal homopolymers: The homopolymers are available in several viscosity ranges that meet a variety of processing and end-use needs. The higher viscosity materials are generally used for extrusions and for molded parts requiring maximum toughness; the lower viscosity grades are used for injection molding. Elastomer-modified grades offer greatly improved toughness.

Properties: Acetal homopolymer resins have high tensile strength, stiffness, resilience, fatigue endurance, and moderate toughness under repeated impact. Delrin 100, a high-impact grade, is the toughest acetal. Delrin 100 ST is a super tough grade, delivering up to seven times greater toughness than unmodified acetal in Izod impact tests and up to 30 times greater toughness as measured by Gardner impact tests.

Homopolymer acetals have high resistance to organic solvents, excellent dimensional stability, a low coefficient of friction, and outstanding abrasion resistance among thermoplastics. The general-purpose resins can be used over a wide range of environmental conditions; special, UV-stabilized grades are recommended for applications requiring long-term exposure to weathering. However, prolonged exposure to strong acids and bases outside the range of pH 4 to 9 is not recommended.

Acetal homopolymer has the highest fatigue endurance of any unfilled commercial thermoplastic. Under completely reversed tensile and compressive stress, and with 100% relative humidity (at 73°F), fatigue endurance limit is 4,500 psi at 10^6 cycles. Resistance to creep is excellent. Moisture, lubricants, and solvents including gasoline and gasohol have little effect on this property, which is important in parts incorporating self-threading screws or interference fits.

The low friction and good wear resistance of acetals against metals makes these resins suitable for use in cams and gears having internal bearings. The coefficient of friction (nonlubricated) on steel, in a rotating thrust washer test, is 0.1 to 0.3, depending on pressure; little variation occurs from 73 to 250°F. For even lower friction and wear, PTFE-fiber-filled and chemically lubricated formulations are available.

Properties of low moisture absorption, excellent creep resistance, and

Shorten Your Parts Development Cycle With The Next Shape In Ultra Performance Parts:

Celazole® T-Series Thermoplastics.

Strengths these diverse parts all share with Celazole thermoplastics: shorter overall development times, lower manufactured costs, and performance in your most demanding applications.

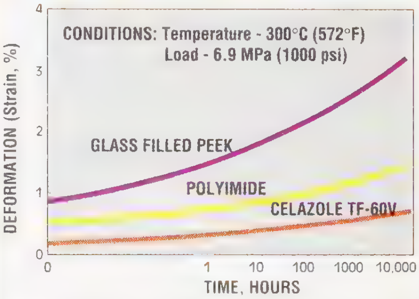
The new T-Series includes four grades which have all the outstanding physical and thermomechanical properties you've come to expect of Celazole:

TU-60	Unreinforced
TF-60V	Glass Reinforced
TF-60C	Carbon Reinforced
TL-60	Self Lubricating

Because they're melt processable, you can achieve unheard of flexibility in development of complex parts. All with the unmatched performance characteristics of sintered polyimides without the brittleness of thermoset polyimides.

Make Celazole T-Series the best part of your next project: Fax us drawings and specifications today, (713)443-7917. It could be the best move on your part.

The Next Shape Of Performance



Creep behavior of glass reinforced thermoformable Celazole, glass reinforced PEEK, and unfilled Polyimide

Piston Rings
- Low friction and outstanding wear resistance
- Low noise
- Continuous operation up to 650° F

Valve Seats
- Little or no creep at very high loads and temperatures exceeding 600° F
- Outstanding overall chemical resistance - no hydrolysis
- High tolerances and metal-like finishes without expensive machining

Hard Disk Carrier
- Dimensional stability
- High temperature resistance (up to 675° F)

High Temperature Electrical Connector
- Operates at temperatures exceeding 600° F
- Outstanding thermal and electrical insulation
- More cost effective than machined ceramic, metal, or polyimide connectors
- Toughness and durability of thermoplastics

Carburetor Link
- Inert in automotive fluids
- Withstands temperatures beyond current polyimide limits
- Close tolerances possible in economical high volumes

Business Machine Components
- Continuous operating temperatures above 600° F
- Excellent wear and dimensional stability
- Complex designs produced economically through melt processing

Copier Roll Bushing
- Exceptional friction/wear resistance
- High temperature (>600° F) dimensional stability
- Lower cost versus machined metal or plastic polyimide components

Hoechst Celanese Corporation
Performance Parts Business
18207 Chisholm Trail Suite 216
Houston, Texas 77060
1(800)874-9357 (713)443-7725

Hoechst Celanese

Hoechst

The name and logo Hoechst is a registered trademark of Hoechst AG

Circle 579

CELAZOLE®
ULTRA-HIGH PERFORMANCE PLASTICS

Celazole T-Series thermoplastics deliver the superior strength of Celazole sintered polybenzimidazole and more in four new, enhanced-strength grades of melt-processable thermoplastics.

Injection moldability assures unheard of flexibility and reduced development cycles in the production and manufacture of complex, high performance parts for a wide range of applications. All with the unmatched performance characteristics of Celazole for extraordinary high temperature resistance and excellent stability with chemicals and hydrolysis.

CELAZOLE® T-SERIES PRODUCT LINE KEY ATTRIBUTES

- Thermal/Mechanical properties superior to Ether Ketone filled systems (over 100°F greater operating temperature range); competitive with PAI and PI
- Able to injection mold final parts thereby eliminating need to perform costly machining operations
- Superior tribological properties versus polyimide and polyamide-imide systems
- Exceptional radiation and cryogenic characteristics
- Improved toughness versus Celazole® U-60 product line

CELAZOLE NONMENCLATURE SYSTEM

MELT PROCESSABLE T-SERIES GRADES

TU-60	Unfilled, Melt Processable PBI
TF-60V	Glass Filled, Melt Processable PBI
TF-60C	Carbon Filled, Melt Processable PBI
TL-60	Self-lubricating, Melt Processable PBI

MECHANICAL PROPERTIES

CELAZOLE® TU-60 TYPICAL PROPERTIES

Property	ASTM Method	English Value	Met
Tensile Strength	D-638	16,000 psi	110
Modulus		700 Kpsi	4.8
Elongation		2.8%	2.8%
Flexural Strength	D-790	24,500 psi	169
Modulus		815 Kpsi	5.6
Compressive Strength	D-695	30,000 psi	207
Modulus		430 Kpsi	3.0

CELAZOLE® TF-60V TYPICAL PROPERTIES

Property	ASTM Method	English Value	Met
Tensile Strength	D-638	26,300 psi	181
Modulus		1900 Kpsi	13.1
Elongation		1.9%	1.9%
Flexural Strength	D-790	35,100 psi	242
Modulus		1850 Kpsi	12.8
Compressive Strength	D-695	32,000 psi	221
Modulus		530 Kpsi	3.7

CELAZOLE® TF-60C TYPICAL PROPERTIES

Property	ASTM Method	English Value	Metr
Tensile Strength	D-638	29,000 psi	200
Modulus		3100 Kpsi	21.4
Elongation		1.7%	1.7%
Flexural Strength	D-790	46,000 psi	317
Modulus		2900 Kpsi	20.0
Compressive Strength	D-695	32,000 psi	221
Modulus		555 Kpsi	3.8

CELAZOLE® TL-60 TYPICAL PROPERTIES

Property	ASTM Method	English Value	Metr
Tensile Strength	D-638	16,300 psi	112
Modulus		2300 Kpsi	15.9
Elongation		1.2%	1.2%
Flexural Strength	D-790	26,400 psi	182
Modulus		2110 Kpsi	14.5
Compressive Strength	D-695	18,000 psi	124
Modulus		455 Kpsi	3.1

THERMAL PROPERTIES

CELAZOLE® TU-60

Property	ASTM Method	English Value	Metr
Coefficient of Linear Thermal Expansion	TMA		
75-300°F		19.1 x 10^{-6} in/in°F	34µ
390-570°F		39.4 x 10^{-6} in/in°F	70 µ
Heat Capacity @ 158°F	DSC	0.28 Btu/lb°F	1170
Heat Deflection Temperature @ 264 psi	D648	491°F	255°
Temperature of Initial (5%) Weight Loss In:			
Air	TGA	930°F	499°
Nitrogen	TGA	930°F	499°

©1992 by Hoechst Celanese Corporation. Issued by the PBI Products Division of Hoechst Celanese Corporation. The Hoechst name and logo are trademarks of Hoechst AG.

To the best of our knowledge, the information contained herein is accurate. However, neither Hoechst Celanese Corporation, its parent company nor any of its affiliates assumes any liability whatsoever for the accuracy of completene information contained herein. Final determination of suitability and whether there is any infringement of patents is the sole responsibility of the user.

Users of any substance must satisfy themselves by independent investigation that the material can be used safely. We may have described certain hazards, but we cannot guarantee that these are the only hazards which exist.

AZOLE® TF-60V

)erty	ASTM Method	English Value	Metric Value
fficient of Linear ermal Expansion 300°F)°-570°F	TMA	 9.6 x 10^{6} in/in°F 18.8x10^{-6} in/in °F	 17 µm/m°C 34 µm/m°C
t Capacity @ 158°F	DSC	0.27 Btu/lb°F	1130J/kg°C
t Deflection mperature @264 psi	D-648	597°F	314°C
iperature of Initial %) Weight Loss In: rogen	TGA	 1125°F 1175°F	 607°C 635°C
rmal Conductivity 75°F	F-433	2.5 Btu in/hr • ft^{2}°F	0.36 W/m°C
ural Strength 550°F odulus @ 550°F	D-790-90	 4220 psi 427 Kpsi	 29.1 MPa 2.9 GPa

AZOLE® TF-60C

)erty	ASTM Method	English Value	Metric Value
fficient of Linear ermal Expansion -300°F 0°-570°F	TMA	 14.7 x 10^{6} in/in°F 54.7x10^{-6} in/in °F	 26 µm/m°C 98 µm/m°C
t Capacity @158°F	DSC	0.28 Btu/lb°F	1170 J/kg °C
t Deflection mperature @264 psi	D-648	619°F	326°C
nperature of Initial %) Weight Loss In: trogen	TGA	 1110°F 1160°F	 599°C 627°C
rmal Conductivity 75°F	F-433	3.1 Btu in/hr • ft^{2}°f	0.45 W/m°C
ural Strength 550°F odulus @ 550°F	D-790-90	 7700 psi 447 Kpsi	 53.1 MPa 3.1 GPa

AZOLE® TL-60

perty	ASTM Method	English Value	Metric Value
efficient of Linear ermal Expansion -300°F 0°-570°F	TMA	 14.7 x 10^{6} in/in°F 51.2x10^{-6} in/in °F	 26 µm/m°C 92 µm/m°C
t Capacity @158°F	DSC	0.28 Btu/lb°F	1170 J/kg°C
t Deflection mperature @264 psi	D-648	600°F	316°C
nperature of Initial %) Weight Loss In: trogen	TGA	 1144°F 1162°F	 618°C 628°C
rmal Conductivity 70°F	F-433	5.3 Btu in/hr • ft^{2}°F	0.76 W/m°C
ural Strength 550°F dulus @ 550°F	D-790-90	 2100 psi 125 Kpsi	 14.5 MPa 1.0 GPa

ECTRICAL PROPERTIES

AZOLE® TU-60

perty	ASTM Method	English Value	Metric Value
ectric Strength	D-149	433 V/mil	433 V/mil
ume Resistivity	D-257	2 x 10^{16} ohm-cm	2 x 10^{16} ohm-cm
ipation Factor kHz kHz	D-150	 0.000 0.001	 0.000 0.001
ectric Constant kHz kHz	D-150	 3.4 3.4	 3.4 3.4
Resistance	D-495	135 seconds	135 seconds

CELAZOLE® TF-60V

Property	ASTM Method	English Value	Metric Value
Dielectric Strength	D-149	398 V/mil	398 V/mil
Volume Resistivity	D-257	1 x 10^{16} ohm-cm	1 x 10^{16} ohm-cm
Dissipation Factor 1 kHz 10 kHz	D-150	 0.000 0.001	 0.000 0.001
Dielectric Constant 1 kHz 10 kHz	D-150	 3.9 3.9	 3.9 3.9
Arc Resistance	D-495	181 seconds	181 seconds

TRIBOLOGICAL PROPERTIES

CELAZOLE® TL-60

Property	ASTM Method	English Value	Metric Value
Wear Rate		0.43 in/1000 hrs	11 mm/1000 hrs
Running Temperature		293°F	145°C
Static Coefficient of Friction		0.30	0.30
Dynamic Coefficient of Friction		0.08	0.08

Test Conditions: Mating Material – 1018 Steel
Pressure – 100 psi
Velocity – 1000 ft/min
Surface Finish – 16 RMS

OTHER PROPERTIES

CELAZOLE® TU-60

Property	ASTM Method	English Value	Metric Value
Specific Gravity		1.3	1.3
Hardness, Rockwell K		50.0	50.0
Hardness, Shore D		90.0	90.0
Poisson's Ratio		0.36	0.36
Water Absorption 24 hours at 73°F	D-750	 0.23%	 0.23%

CELAZOLE® TF-60V

Property	ASTM Method	English Value	Metric Value
Specific Gravity		1.5	1.5
Hardness, Rockwell A		30.0	30.0
Poisson's Ratio		0.34	0.34
Water Absorption 24 hrs @ 73°F	D-750	 0.25%	 0.25%

CELAZOLE® TF-60C

Property	ASTM Method	English Value	Metric Value
Specific Gravity		1.4	1.4
Hardness, Rockwell A		28.0	28.0
Poisson's Ratio		0.39	0.39
Water Absorption 24 hrs @ 73°F	D-750	 0.15%	 0.15%

CELAZOLE® TL-60

Property	ASTM Method	English Value	Metric Value
Specific Gravity		1.4	1.4
Hardness, Rockwell K		24.9	24.9
Poisson's Ration		0.42	0.42
Water Absorption 24 hrs @ 73°F	D-750	 0.20%	 0.20%

Hoechst Celanese Corporation
Performance Parts Business
18207 Chisholm Trail Suite 216
Houston, Texas 77060
1 (800) 874-9357 (713) 443-7725

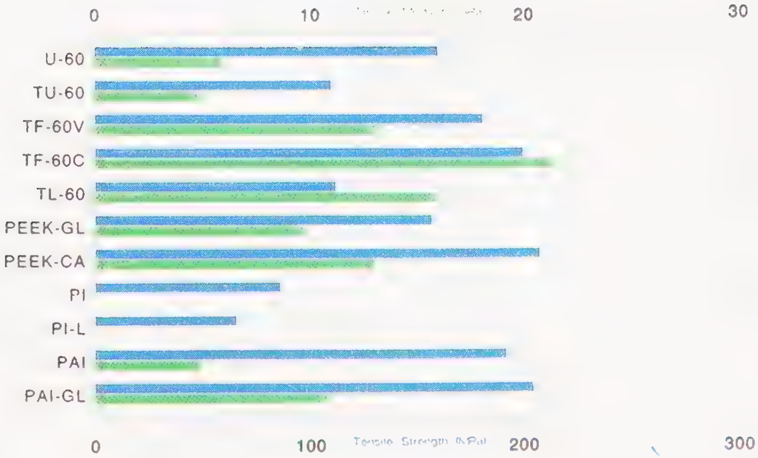
by Hoechst Celanese Corporation. Issued by the PBI Products Division of Hoechst Celanese Corporation. The Hoechst name and logo are trademarks of Hoechst AG

best of our knowledge, the information contained herein is accurate. However, neither Hoechst Celanese Corporation, its parent company nor any of its affiliates assumes any liability whatsoever for the accuracy of completeness of the ation contained herein. Final determination of suitability and whether there is any infringement of patents is the sole responsibility of the user

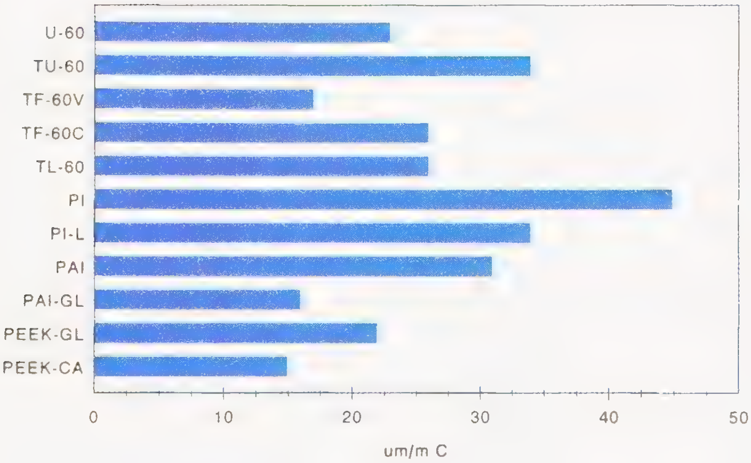
of any substance must satisfy themselves by independent investigation that the material can be used safely. We may have described certain hazards, but we cannot guarantee that these are the only hazards which exist

Circle 580

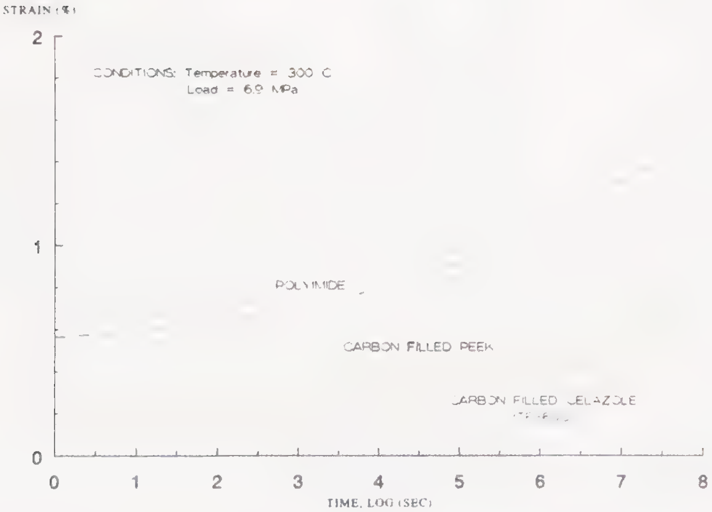
TENSILE PROPERTIE



COEFFICIENT OF THERMAL EXPANSIO



FLEXURAL CREEP PROPERTIES



Hoechst Celanese Corporation
Performance Parts Business
18207 Chisholm Trail Suite 216
Houston, Texas 77060
1(800) 874-9357 (713) 443-7725

Hoechst Celanese

Hoechst

The name and logo Hoechst is a registered trademark of Hoechst

Circle 581

high deflection temperature suit acetal homopolymer for close-tolerance, high-performance parts. Long-term behavior in various environments can be predicted from design handbook data.

Applications: Automotive applications of acetal homopolymer resins include fuel-system and seat-belt components, steering columns, window-support brackets, and handles. Typical plumbing applications that have replaced brass or zinc components are shower heads, ballcocks, faucet cartridges, and various fittings. Consumer items include quality toys, garden sprayers, stereo cassette parts, butane lighter bodies, zippers, and telephone components. Industrial applications of acetal homopolymer include couplings, pump impellers, conveyor plates, gears, sprockets, and springs.

Acetal copolymers: The copolymers have an excellent balance of properties and processing characteristics. Melt temperature can range from 360 to 450°F with little effect on part strength. The resin is available in natural (translucent white) and in a wide range of colors. UV-resistant grades (also available in colors), glass-reinforced grades, low-wear grades, and impact-modified grades are standard. Also available are electroplatable and dimensionally stable, low-warpage grades.

Properties: Acetal copolymers have high tensile and flexural strength, fatigue resistance, and hardness. Lubricity is excellent. They retain much of their toughness through a broad temperature range and are among the most creep resistant of the crystalline thermoplastics. Moisture absorption is low, permitting molded parts to serve reliably in environments involving humidity changes.

Good electrical properties, combined with high mechanical strength and a UL electrical rating of 100°C, qualify these materials for electrical applications requiring long-term stability.

Acetal copolymers have excellent resistance to chemicals and solvents. For example, specimens immersed for 12 months at room temperature in various inorganic solutions were unaffected except by strong mineral acids — sulfuric, nitric, and hydrochloric. Continuous contact is not recommended with strong oxidizing agents such as aqueous solutions containing high concentrations of hypochlorite ions. Solutions of 10% ammonium hydroxide and 10% sodium chloride discolor samples in prolonged immersion, but physical and mechanical properties are not significantly changed. Most organic reagents tested have no effect, nor do mineral oil, motor oil, or brake fluids. Resistance to strong alkalies is exceptionally good; specimens immersed in boiling 50% sodium hydroxide solution and other strong bases for many months show no property changes.

Strength of acetal copolymer is only slightly reduced after aging for one year in air at 240°F. Impact strength holds constant for the first six months, and falls off about one-third during the next six-month period. Aging in air at 180°F for two years has little or no effect on properties, and immersion for one year in 180°F water leaves most properties virtually unchanged. Samples tested in boiling water retain nearly original tensile strength after nine months.

Applications: Industrial and automotive applications of Celcon acetal copolymer include gears, cams, bushings, clips, lugs, door handles, window cranks, housings, and seat-belt components. Plumbing products such as valves, valve stems, pumps, faucets, and impellers utilize the lubricity and corrosion and hot-water resistance of the copolymer. Mechanical components that require dimensional stability, such as watch gears, conveyor links, aerosols, and mechanical pen and pencil parts, are other uses. Applications for the FDA-approved grades include milk pumps, coffee spigots, filter housings, and food conveyors. Parts that require greater load-bearing stability at elevated temperatures, such as cams, gears, TV tuner arms and automotive underhood components are molded from glass-fiber-reinforced grades.

Acrylic

Acrylic thermoplastics are known for their crystal clarity and outstanding weatherability. They are available in cast sheet, rod, and tube; extruded sheet and film; and compounds for injection molding and extrusion.

Cell-cast sheet is produced in several sizes and thicknesses. The largest sheets available are 120 × 144 in., in thicknesses from 0.030 to 4.25 in. Continuous cast material is supplied as flat sheet to ¼ in. thick, in widths to 9 ft. Acrylic sheet cast by the continuous process (between stainless-steel belts) is more uniform in thickness than cell-cast sheet. Cell-cast sheet, on the other hand, which is cast between glass plates, has superior optical properties and surface quality. Also, cell-cast sheet is available in a greater variety of colors and compositions. Cast acrylic sheet is supplied in general-purpose grades and in ultraviolet-absorbing, mirrored, super-thermoformable and cementable grades, and with various surface finishes. Sheets are available in transparent, translucent, and opaque colors.

Acrylic film is available in 2, 3, and 6-mil thicknesses, in clear form and in colors. It is supplied in rolls to 60 in. wide, principally for use as a protective laminated cover over other plastic materials.

Injection-molding and extrusion compounds are available in both standard and high-molecular-weight grades. Property differences between the two formulations are principally in flow and heat resistance. Higher molecular-weight resins have lower melt-flow rates and greater hot strength during processing. Lower molecular-weight grades flow more readily and are designed for making complex parts in hard-to-fill molds. Also available are high-impact molding grades, which provide the same transparency and weatherability as the conventional acrylics.

Properties: Acrylic plastics transmit and control light, resist weather, are stable against discoloration, and have superior dimensional stability and an excellent combination of structural and thermal properties. Clear acrylic plastic is as transparent as the finest optical glass. It has a light transmittance of 92%, exceptionally low haze level of approximately 1%, and an index of refraction of 1.49 — high enough for use in lenses and other optical applications.

Colorants produce a full spectrum of transparent, translucent, or opaque colors. Most colors can be formulated for long-term outdoor durability. Acrylics are normally formulated to filter ultraviolet energy in the 360-nm and lower band. Other formulations are opaque to UV light or provide reduced UV transmission.

Mechanical properties of acrylics are high for short-term loading. However, for long-term service, tensile stresses must be limited to 1,500 psi to avoid crazing or surface cracking.

The moderate impact resistance of standard formulations is maintained even under conditions of extreme cold. High-impact grades have considerably higher impact strength than standard grades at room temperature, but impact strength decreases as temperature drops. Special formulations ensure compliance with Underwriters' Laboratories standards for bullet resistance.

Although acrylic plastics are among the most scratch resistant of the thermoplastics, normal maintenance and cleaning operations can scratch and abrade them. Special abrasion-resistant sheet is available that has the same optical and impact properties as standard grades.

Toughness of acrylic sheet, as measured by resistance to crack propagation, can be improved severalfold by inducing molecular orientation during forming. Jet-aircraft cabin windows, for example, are made from oriented acrylic sheet.

Acrylic sheet and moldings resist solutions of inorganic acids and alkalies and aliphatic hydrocarbons such as VM&P naphtha, as well as most detergent solutions and cleaning agents. They are attacked, however, by chlorinated and aromatic hydrocarbons, esters, and ketones.

Transparency, gloss, and dimensional stability of acrylics are virtually unaffected by years of exposure to the elements, salt spray, or corrosive atmospheres. These materials withstand exposure to light from fluorescent lamps without darkening or deteriorating. They ultimately discolor, however, when exposed to high-intensity UV light below 265 nm. Special formulations resist UV emission from light sources such as mercury-vapor and sodium-vapor lamps.

Applications: Cast acrylic sheet is used in aircraft, boat, mass transit, architectural, and protective glazing; internally illuminated outdoor signs, lighting diffusers, and skylights; and product prototypes and demonstration models. Special ultraviolet-absorbing grades are used for document preservation in museums and for various photographic applications.

Acrylic film is used as a laminated protective surface on ABS, PVC, or other plastic sheet that is thermoformed into parts requiring resistance to outdoor weathering. Examples include motorcycle shrouds, recreational-vehicle panels, residential siding, and transformer housings.

Acrylic moldings are used for light-control lenses in lighting fixtures, camera lenses, vending-machine parts, and appliance panels, knobs, and housings. Automotive applications include lenses for taillights and parking lights, instrument panels, nameplates, medallions, and dials. A modified molding compound contains an impact modifier to increase toughness. Parts molded from these durable transparent materials include automotive dials, housewares, piano keys, medical instruments, and toys.

Specially formulated acrylic sheet is available for deeply formed components such as tub-shower units, which are subsequently backed with glass-fiber-reinforced polyester. Chemical resistance of this sheet is superior to that of conventional sheet.

Sheet extruded from the high-impact molding grade is used for signs, thermoformed products, toys, and glass-fiber-polyester-backed components such as camper tops, furniture, and recreational-vehicle bodies.

Acrylics

ASTM test	Property	Cast sheet	MOLDING GRADE	
			Standard	High impact
	PHYSICAL			
D792	**Specific gravity**	1.19	1.19	1.15-1.17
D792	**Specific volume** (in.^{3}/lb)	23.3	23.3	24.1
D570	**Water absorption, 24 h,** ⅛-in. thk (%)	0.2	0.3	0.3
	MECHANICAL			
D638	**Tensile strength** (psi)	10,500	10,500	5,400-7,000
D638	**Elongation** (%)	5	5	50
D638	**Tensile modulus** (10^5 psi)	4.5	4.3	2.2-3.2
D790	**Flexural strength** (psi)	16,500	16,000	7,000-10,500
D790	**Flexural modulus** (10^5 psi)	4.5	4.5	0.65-2.5
D256	**Impact strength,** Izod (ft-lb/in. of notch)	0.4	0.4	0.6-1.2
D785	**Hardness,** Rockwell	M100-102	M95	R99-M68
	THERMAL			
D696	**Coef of thermal expansion** (10^{-5} in./in.-°C)	3.9	3.6	3.8
D648	**Deflection termperature** (°F)			
	At 264 psi	200-215	198	170-190
	At 66 psi	225	214	187
	ELECTRICAL			
D149	**Dielectric strength** (V/mil) Short time, ⅛-in. thk	500	500	383-450
D150	**Dielectric constant**			
	At 1 kHz	3.3	3.3	3.9
	At 1 MHz	2.5	2.3	2.5-3.0
D150	**Dissipation factor**			
	At 1 kHz	0.04	0.04	—
	At 1 MHz	0.02-0.03	0.02-0.03	0.01-0.02
D257	**Volume resistivity** (ohm-cm) At 73°F, 50% RH	$>10^{17}$	$>10^{17}$	$>10^{15}$
D495	**Arc resistance** (s)	No track	No track	No track
	OPTICAL			
D542	**Refractive index**	1.49	1.49	1.49
D1003	**Transmittance** (%)	92	92	90

Alkyd

Alkyd molding compounds are based on unsaturated polyester-type resins, which are combined with crosslinking monomers, catalysts, reinforcements, lubricants, and fillers. The formulations are similar to those of thermosetting polyesters but with lower amounts of monomers.

Alkyds are part of the group of materials that includes bulk-molding compounds (BMCs) and sheet-molding compounds (SMCs). They are processed by compression, transfer, or injection molding. Fast molding cycles at low pressure make alkyds easier to mold than many other thermosets.

Alkyds are furnished in granular compounds, extruded ropes or logs, bulk-molding compound, flake, and puttylike sheets. Except for the putty grades, which may be used for encapsulation, these compounds contain fibrous reinforcement. Generally, the fiber reinforcement in rope and logs is longer than that in granular compounds and shorter than that in flake compounds. Thus, strength of these materials is between those of granular and flake compounds. Because the fillers are opaque and the resins are amber, translucent colors are not possible. Opaque, light shades can be produced in most colors, however.

Properties: Low-moisture absorption and excellent dimensional stability and electrical properties are the outstanding characteristics of most alkyd molding compounds. For electrical-grade materials, absorption can be as low as 0.5%. Alkyds are relatively low-loss materials, especially the mineral-filled and glass-filled grades. Those containing cellulose may have higher loss characteristics and "drift" with

illed amino compounds

STM or L test	Property	UREA	MELAMINE COMPOUNDS			
			Filler			
		Alpha cellulose	Alpha cellulose	Macerated fabric	Asbestos	Glass fiber
	PHYSICAL					
792	**Specific gravity**	1.47-1.52	1.47-1.52	1.5	1.7-2.0	1.8-2.0
792	**Specific volume** (in.^{3}/lb)	18.8-18.2	18.8-18.2	18.5	16.3-13.8	13.8-10.0
570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.4-0.8	0.1-0.6	0.3-0.6	0.08-0.14	0.09-0.21
	MECHANICAL					
638	**Tensile strength** (psi)	5,500-7,000	7,000-13,000	8,000-10,000	5,500-6,500	5,000-10,000
638	**Elongation** (%)	0.5-1.0	0.6-0.9	0.6-0.8	0.3-0.45	—
638	**Tensile modulus** (10^5 psi)	13-14	13.5	14-16	19.5	24
790	**Flexural strength** (psi)	11,000-18,000	12,000-15,000	12,000-15,000	7,400-10,000	13,000-24,000
790	**Flexural modulus** (10^5 psi)	14-15	11	14	18	24
256	**Impact strength,** Izod (ft-lb/in. of notch)	0.27-0.34	0.24-0.35	0.6-1.0	0.3-0.4	0.6-18
785	**Hardness,** Rockwell M	110-120	120	120	110	115
	THERMAL					
177	**Thermal conductivity** (10^{-4} cal-cm/sec-cm^2-°C)	10.1	7.0-10.1	10.6	13-17	11.5
696	**Coef of thermal expansion** (10^{-5} in./in-°C)	2.2-3.6	2.0-5.7	2.5-2.8	2.0-4.5	1.5-1.7
648	**Deflection temperature** (°F) At 264 psi	266	360	310	265	400
JL 94	**Flammability rating**	V-0*	V-0†	—	—	V-0
	ELECTRICAL					
149	**Dielectric strength** (V/mil)					
	Short time, ⅛-in. thk	330-370	270-300	250-350	410-430	170-300
	Step by step	220-250	240-270	200-300	280-320	170-240
150	**Dielectric constant** At 1 kHz	—	7.8-9.2	7.1-7.8	9.0	—
150	**Dissipation factor** At 1 kHz	—	0.015-0.036	0.03-0.05	0.07	—
257	**Volume resistivity** (ohm-cm) At 73° F, 50% RH	0.5 to 5.0×10^{11}	0.8 to 2.0×10^{12}	1.0 to 3.0×10^{11}	1.2×10^{12}	0.9 to 2.0×10^{11}
495	**Arc Resistance** (s)	100-135	125-136	122-128	20-180	180-186

Applies to specimens thicker than 1/16 in. †1/16 in.

temperature and humidity changes.

Molded alkyd parts resist weak acids, organic solvents, and hydrocarbons such as alcohol and fatty acids; they are attacked by alkalies.

Glass and asbestos-filled compounds have better heat resistance than the cellulose-modified types. Depending on type, alkyds can be used continuously to 350°F and, for short periods, to 450°F. Alkyd molding compounds retain their dimensional stability and electrical and mechanical properties over a wide temperature range.

Halogen and/or phosphorus-bearing alkyd molding compounds with antimony trioxide added provide improved flame resistance. Other flame-resistant compounds are available that do not contain halogenated resins. Many grades are UL-rated at 94V-0 in sections under 1⁄16 in. Flammability ratings depend on specific formulations, however, and can vary from 94HB to V-0. Flammability ratings also vary with section thickness.

Applications: High-impact grades of alkyd compounds (with high-glass content) are used in military switchgear, electrical terminal strips, and relay and transformer housings and bases. Mineral-filled grades, which can be modified with cellulose to reduce specific gravity and cost, are used in automotive ignition parts, radio and TV components, switchgear, and small appliance housings. Alkyds with all-mineral fillers have high moisture resistance and are particularly suited for electronic components. Grades are available that can withstand the temperatures of vapor-phase soldering.

Allyl

Esters in the allyl family consist principally of diallyl phthalate (DAP) and diallyl isophthalate (DAIP). Both are used as monomers and as prepolymers, which are readily converted to thermoset molding compounds and resins for preimpregnated glass cloth and paper. Allyls are also used as cross-linking agents for unsaturated polyesters.

Compounds based on allyl prepolymers are reinforced with fibers (glass, polyester, or acrylic) and filled with particulate materials to improve properties. Glass fiber imparts maximum mechanical properties, acrylic fiber provides the best electrical properties, and polyester fiber improves impact resistance and strength in thin sections. Compounds can be made in a wide range of colors because the resin is essentially colorless.

Prepregs (preimpregnated glass cloth) based on allyl prepolymers can be formulated for short cure cycles. They contain no toxic additives, and they offer long storage stability and ease of handling and fabrication. Properties such as flame resistance can be incorporated. The allyl prepolymers contribute excellent chemical resistance and good electrical properties.

Properties: Allyl molding compounds do not corrode copper or plated inserts or contacts, even in hot, humid environments. Molded parts maintain their high electrical properties at high temperature (to 370°F for DAP and 400°F for DAIP) and humidity levels. Allyl materials are also characterized by excellent dimensional stability and resistance to moisture, chemicals, and liquid oxygen. They withstand strong and weak acids, alkalies, and organic solvents, even at elevated temperatures.

Allyl moldings have low mold shrinkage and postmold shrinkage — attributed to their nearly complete addition reaction in the mold — and have excellent stability under prolonged or cyclic heat exposure. Advantages of allyl systems over polyesters are freedom from styrene odor, low toxicity, low-evaporation losses during evacuation cycles, no subsequent oozing or bleed-out, and long-term retention of electrical-insulation characteristics.

Applications: Diallyl phthalate monomer is used as a nonvolatile cross-linker in polyester compounds to improve properties and handling characteristics. Deflection temperature is raised to 400°F or higher, dimensional stability and electrical properties are upgraded, and flexural properties are retained for long periods at elevated temperatures. DAP is also used in combination with polyester resin systems for low-pressure decorative laminates. Allylic resins in powder and liquid form are used for coatings and for impregnating materials.

Allyl prepolymers are particularly suited for critical electronic components that serve in severe environmental conditions. Chemical inertness qualifies the resins for molded pump impellers and other chemical-processing equipment. Their ability to withstand steam environments permits uses in sterilizing and hot-water equipment. Because of their excellent flow characteristics, diallyl-phthalate compounds are used for parts requiring extreme dimensional accuracy. Modified resin systems are used for encapsulation of electronic devices such as semiconductors and as sealants for metal castings.

A major application area for allyl compounds is electrical connectors, used in communications, computer, and aerospace systems. The high thermal resistance of these materials permits their use in vapor-phase soldering operations. Uses for prepolymers include arc-track-resistant compounds for switchgear and TV components. Other representative uses are insulators, encapsulating shells, potentiometer components, circuit boards, and housings.

Allyl-based prepregs are used to make lightweight, intricate parts such as radomes, printed-circuit boards, tubing, ducting, and aircraft parts. Another use is in copper-clad laminates for high-performance printed-circuit boards.

Alkyds

ASTM test	Property	FILLER Mineral	 Glass
	PHYSICAL		
D792	**Specific gravity**	1.60-2.30	2.0-2.3
D570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.05-0.50	0.03-0.5
	MECHANICAL		
D638	**Tensile strength** (psi)	3,000-9,000	4,000-9,500
D638	**Tensile modulus** (10^5 psi)	5-30	20-28
D790	**Flexural strength** (psi)	6,000-17,000	8,500-26,000
D790	**Flexural modulus** (10^5 psi)	20	20
D256	**Impact strength,** Izod (ft-lb/in. of notch)	0.3-0.5	0.5-16
D785	**Hardness,** Rockwell	E98	E95
	THERMAL		
C177	**Thermal conductivity** (10^{-4} cal-cm/sec-cm^2-°C)	12.2-25	15-25
D696	**Coef of thermal expansion** (10^{-5} in./in.-°C)	2-5	1.5-3.3
D648	**Deflection temperature** (°F) At 264 psi	350-500	400-500
	ELECTRICAL		
D149	**Dielectric strength,** (V/mil) Short time, ⅛-in. thk	350-450	250-530
D150	**Dielectric constant** At 1 kHz	5.5-6.0	—
D150	**Dissipation factor** At 1 kHz	0.02-0.04	—
D257	**Volume resistivity** (ohm-cm) At 73°F, 50% RH	10^{13}-10^{15}	—
D495	**Arc resistance** (s)	180+	180+

DAP molding compounds

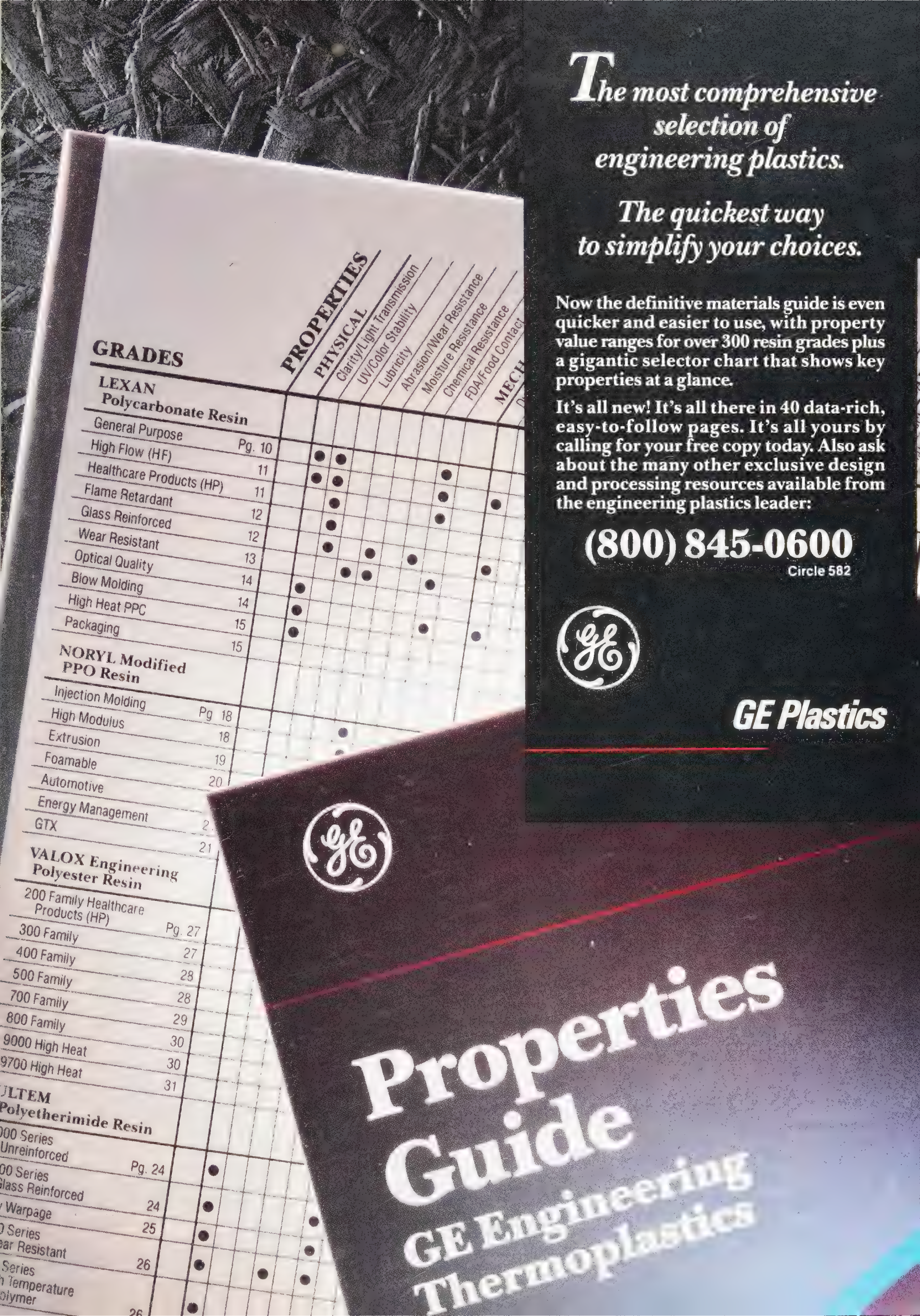
ASTM test	Property	FILLER Polyester	 Long glass	 Short glass	Arc-track resistant
	PHYSICAL				
D792	**Specific gravity**	1.39-1.42	1.70-1.90	1.6-1.8	1.87
D792	**Specific volume** (in.^{3}/lb)	19.96-19.54	17.90-16.32	17.34-15.42	14.84
D570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.2	0.05-0.2	0.05-0.2	0.14
	MECHANICAL				
D638	**Tensile strength** (psi)	5,000	9,000	7,000	7,000-10,000
D790	**Flexural strength** (psi)	11,500-12,500	18,000	16,000	24,000
D790	**Flexural modulus** (10^5 psi)	6.4	16	17	19
D256	**Impact strength,** Izod (ft-lb/in. of notch)	4.5-12	6.0	0.8	3.6
D785	**Hardness,** Rockwell M	108	105-110	105-110	112
	THERMAL				
C177	**Thermal conductivity** (10^{-4} cal-cm/sec-cm^2-°C)	—	14-16	14-15	15-17
D696	**Coef of thermal expansion** (10^{-5} in./in.-°C)	—	2.0-3.0	2.0-3.0	23-27
D648	**Deflection temperature** (°F) At 264 psi	290	450	420	>572
	ELECTRICAL				
D149	**Dielectric strength** (V/mil) Step by step, ⅛-in. thk	400	385	400	400
D150	**Dielectric constant** At 1 kHz	0.008	0.004-0.006	0.006	0.003-0.008
D150	**Dissipation factor** At 1 kHz	3.6	4.2	4.4	4.1-4.5
D257	**Volume resistivity** (ohm-cm) At 73°F, 50% RH	2-3 x 10^{15}	2-3 x 10^{15}	2-3 x 10^{15}	10^{16}
D495	**Arc resistance** (s)	125	140	135	125-180
	FRICTIONAL				
—	**Coefficient of friction**			Stat/Dyn	
	Self	—	—	0.14/0.13	—
	Against steel	—	—	0.20/0.19	—

Amino

Melamine and urea are the principal commercial thermosetting polymers called aminos. The amino resins are formed by an addition reaction of formaldehyde and compounds containing NH_2 amino groups. They are supplied as liquid or dry resins and filled molding compounds. Applying heat in the presence of a catalyst converts the materials into strong, hard products. Aminos are used as molding compounds, laminating resins, wood adhesives, coatings, wet-strength paper resins, and textile-treating resins.

The base resin used in urea and melamine molding compounds is water-white and transparent. Translucent and opaque colors are produced by adding pigments and opacifying agents. Cellulose fibers improve strength and dimensional stability and reduce light transmission.

Properties: Moldings made from amino compounds are hard, rigid, abrasion resistant, and have high resistance to deformation under load. They do not impart taste or odor to foods, and they have excellent electrical insulation characteristics. Melamines are



GRADES

PROPERTIES

PHYSICAL

Clarity/Light Transmission

UV/Color Stability

Lubricity

Abrasion/Wear Resistance

Moisture Resistance

Chemical Resistance

FDA/Food Contac

MECH

LEXAN Polycarbonate Resin

General Purpose	Pg. 10
High Flow (HF)	11
Healthcare Products (HP)	11
Flame Retardant	12
Glass Reinforced	12
Wear Resistant	13
Optical Quality	14
Blow Molding	14
High Heat PPC	15
Packaging	15

NORYL Modified PPO Resin

Injection Molding	Pg 18
High Modulus	18
Extrusion	19
Foamable	20
Automotive	2
Energy Management	
GTX	21

VALOX Engineering Polyester Resin

200 Family Healthcare Products (HP)	Pg. 27
300 Family	27
400 Family	28
500 Family	28
700 Family	29
800 Family	30
9000 High Heat	30
9700 High Heat	31

ULTEM Polyetherimide Resin

000 Series Unreinforced	Pg. 24
00 Series ilass Reinforced	24
Warpage	25
0 Series ear Resistant	26
Series n Temperature olymer	26

The most comprehensive selection of engineering plastics.

The quickest way to simplify your choices.

Now the definitive materials guide is even quicker and easier to use, with property value ranges for over 300 resin grades plus a gigantic selector chart that shows key properties at a glance.

It's all new! It's all there in 40 data-rich, easy-to-follow pages. It's all yours by calling for your free copy today. Also ask about the many other exclusive design and processing resources available from the engineering plastics leader:

(800) 845-0600

Circle 582

GE Plastics

superior to ureas in resistance to acids, alkalies, heat, boiling water, and for applications involving wet/dry cycling.

Urea and some melamine molding compounds have flammability ratings of 94V-0. Melamines containing alpha cellulose, mineral, or glass fibers have the greatest flame resistance. These materials can be used for appliance parts classified by UL as indirect supports of current-carrying parts.

Below −70°F, urea moldings become brittle, but electrical properties are not affected. Extended exposure above 170°F is not recommended for ureas because of the effect on color. At 300°F, color change and blistering may occur after exposure of less than one hour.

Melamine compounds containing cellulose or flock fillers are stable in the range of −70 to 250°F. Asbestos or glass-filled formulations are stable to 400°F. Above 210°F, however, color changes may occur.

Melamines and ureas are not resistant to strong oxidizing acids or strong alkalies, but they can be used safely with conventional household chemicals such as naphtha and detergents. They are unaffected by organic solvents such as acetone, carbon tetrachloride, ethyl alcohol, heptane, and isopropyl alcohol. Petroleum, paraffin hydrocarbons, gasoline, kerosene, motor oil, aromatic hydrocarbons, and fluorinated hydrocarbons (Freon) have no apparent effect on urea and melamine moldings. Dimensional stability is good, but moldings do swell and shrink slightly in varying moisture conditions. Baking of molded parts accelerates postmold shrinkage and improves dimensional stability, dielectric strength, and dissipation factor.

Applications: Typical applications for cellulose-filled urea resins include circuit breakers, receptacles, and other electrical wiring devices, toaster and other appliance bases, pushbuttons, knobs, handles, piano keys, and camera parts.

Cellulose-filled melamine is used principally for dinnerware. Other applications include utensil handles, food-service trays, and housings for electric shavers and mixers. Industrial melamine compounds are used for meter blocks, connector plugs, automotive and aircraft ignition parts, standoff terminals, coil forms, and switch housings.

In liquid form, both urea and melamine resins are used as baking-enamel coatings, particleboard binders, and paper and textile treatment materials. Both resins are also used in compounding adhesives. Melamine, the more durable of the two, is waterproof, which qualifies melamine-based adhesives for exterior use.

Cellulosics

ASTM or UL test	Property	Cellulose acetate	Cellulose proplonate	Cellulose acetate butyrate	Ethyl cellulose
	PHYSICAL				
D792	**Specific gravity**	1.22-1.34	1.16-1.24	1.15-1.22	1.09-1.17
D792	**Specific volume** (in.^{3}/lb)	22.7-20.6	23.4-22.4	24.1-22.7	25.5-23.6
D570	**Water absorption** 24 h, ⅛-in. thk (%)	1.7-4.5	1.2-2.8	0.9-2.2	0.8-1.8
	MECHANICAL				
D638	**Tensile strength** (psi)	2,200-6,900	1,400-7,200	1,400-6,200	3,000-4,800
D638	**Tensile modulus** (10^5 psi)	0.65-4.0	0.6-2.15	0.5-2.0	2.2-2.5
D790	**Flexural strength** (psi)	2,500-10,400	1,700-10,600	1,800-9,250	4,700-6,800
D790	**Flexural modulus** (10^5 psi)	1.2-3.6	1.15-3.7	0.9-3.0	—
D256	**Impact strength,** Izod (ft-lb/in. of notch)	1.0-7.3	1.0-10.3	1.1-9.1	3.0-8.0
D785	**Hardness,** Rockwell R	To 122	To 115	To 112	79-106
	THERMAL				
C177	**Thermal conductivity** 10^{-4} cal-cm/sec-cm^2-°C)	4-8	4-8	4-8	3.8-7.0
D696	**Coef of thermal expansion** (10^{-5} in./in.-°C)	8-16	11-17	11-17	10-20
D648	**Deflection temperature** (°F)				
	At 264 psi	111-195	111-228	113-202	115-190
	At 66 psi	120-209	147-250	130-227	170-180
UL 94	**Flammability rating**	V-2, HB	HB	HB	—
	ELECTRICAL				
D149	**Dielectric strength*** (V/mil) Short time, ⅛-in. thk	250-600	300-500	250-400	350-500
D150	**Dielectric constant** At 1 kHz	3.2-7.0	3.3-4.0	3.4-6.4	3.0-4.1
D150	**Dissipation factor** At 1 kHz	0.01-0.10	0.01-0.05	0.01-0.04	0.002-0.020
D257	**Volume resistivity** (ohm-cm) At 73° F, 50% RH	10^{10}-10^{14}	10^{12}-10^{16}	10^{11}-10^{15}	10^{12}-10^{14}
D495	**Arc resistance** (s)	50-310	175-190	—	60-80
	OPTICAL				
D542	**Refractive Index**	1.46-1.50	1.46-1.49	1.46-1.49	—
D1003	**Transmittance†** (%)	80-92	80-92	80-92	—

*At 500 V/s rate of rise. †For ⅛-in. thick specimen.

Cellulosics

Cellulosics are synthetic plastics, but they are not synthetic polymers; they are made from a naturally occurring polymer, cellulose, which is obtained from wood pulp and cotton linters. Cellulose can be made into a film (cellophane) or into a fiber (rayon), but is must be chemically modified to produce a thermoplastic material.

The resins used for plastics production are cellulose acetate, cellulose acetate butyrate, and cellulose propionate, all of which are cellulose esters, and ethyl cellulose, which is a cellulose ether. The plastics produced from them are commonly referred to as "acetate," "butyrate," "propionate," and "ethyl cellulose." They are processed by conventional thermoplastic processes.

The cellulosic plastics are supplied in a wide range of transparent, translucent, and opaque colors, including pearlescents and mottles. Clear resins are available in all except ethyl cellulose, which is light amber in uncolored formulations.

Properties: Because the cellulosics can be compounded with many different plasticizers in widely varying concentrations, property ranges are broad. These materials are normally specified by flow (defined in ASTM D569), which is controlled by plasticizer content. Hard flows of (low plasticizer content) are relatively hard, rigid, and strong. Soft flows (higher plasticizer content) are tough, but less hard, less rigid, and less strong. They also process at lower temperatures. Thus, within available property ranges listed, no one formulation can provide all properties to the maximum degree. Most commonly used formulations are in the middle flow ranges.

Molded cellulosic parts can be used

From The Best Converted Film Source On Earth Comes The Best Thermal Blanket Material In Space

JPL's selection of Courtaulds Performance Films' Thermal Blanket material for Galileo is a reflection of JPL's confidence in Performance Film's quality.

Courtaulds Performance Films is the largest and most capable supplier of converted films on earth.

Now Performance Films provides a wide range of standard and customer specified film products for thermal radiative control of spacecraft. Films to meet any thermal blanket requirement are manufactured to meet particular aerospace specifications and applicable MIL standards.

Combining metallic coatings with reactively sputtered indium tin oxide (ITO) gives Performance Films' thermal blanket materials excellent resistance to static charge build-up and protection from atomic oxygen attack.

For more information, contact Courtaulds Performance Films today. 21034 Osborne Street, Canoga Park, CA 91304-1732 • Telephone: (818) 882-5744 • Fax: (818) 882-6519

COURTAULDS
PERFORMANCE FILMS

Industrial
Products

Circle 583

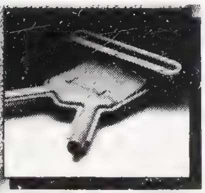
MAKE TOUGHER PARTS FASTER, EASIER, AT LOWER COST

Only thermoforming with KYDEX® sheet gives you this unique combination of advantages:

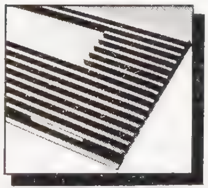
- ▶ Inherent fire retardancy across several grades.
- ▶ 80 to 90% lower mold costs than injection molding; 3 - 4 times faster prototyping and tooling.
- ▶ Outstanding rigidity, resilience, abrasion/impact/chemical resistance, dimensional stability, and modulus of elasticity.
- ▶ Fast, easy secondary operations.
- ▶ Over 200 developed colors in a range of surface textures, gauges, and sheet sizes.

For a free color sample kit with engineering guide, please contact:

Kleerdex Company
100 Gaither Drive
Mount Laurel, NJ 08054
Tel: **800-325-3133**
Fax: **609-866-9728**



AIRCRAFT AIR DIFFUSER



COMPUTER VENT GRILLE

NECK BRACE

FIREFIGHTER AIR PACK HOUSING

KYDEX®

Circle 584

ULTRADUR®

thermoplastic polyester (PBT)

FOR MORE INFORMATION, CALL:

1-800-BC-RESIN

Other BASF Plastic Materials:

- Ultramid® nylon 6, 6.6, 6.10, copolymers and 6/6T (PA)
- Ultraform® acetal copolymer (POM)
- Luran® styrene acrylonitrile (SAN)
- Luran® S acrylonitrile/styrene/acrylate (ASA)
- Terlux™ clear (ABS)
- Ultrason™ E polyethersulfone (PES)
- Ultrason™ S polysulfone (PSU)
- Ultrapek™ polyaryletherketone (PAEK)
- Elastocell® suspension components

BASF Corporation
Plastic Materials
100 Cherry Hill Road
Parsippany, NJ 07054

BASF

Circle 585

in service over broad temperature ranges and are particularly tough at very low temperatures. Ethyl cellulose is outstanding in this respect. These materials have low specific heat and low thermal conductivity — characteristics that give them a pleasant feel.

Dimensional stability of butyrate, propionate, and ethyl cellulose is excellent. Plasticizers used in these materials do not evaporate significantly and are virtually immune to extraction by water. Water absorption (which causes dimensional change) is also low, that of ethyl cellulose being lowest. The plasticizers in acetate are not as permanent as those in other plastics, however, and water absorption of this material is slightly higher.

Butyrate and propionate are highly resistant to water and most aqueous solutions except strong acids and strong bases. They resist nonpolar materials such as aliphatic hydrocarbons and ethers, but they swell or dissolve in low-molecular-weight polar compounds such as alcohols, esters, and ketones, as well as in aromatic and chlorinated hydrocarbons. Acetate is slightly less resistant than butyrate and propionate to water and aqueous solutions, and slightly more resistant to organic materials. Ethyl cellulose dissolves in all the common solvents for this polymer, as well as in such solvents as cyclohexane and diethyl ether. Like the cellulose esters, ethyl cellulose is highly resistant to water.

Although unprotected cellulosics are generally not suitable for continuous outdoor use, special formulations of butyrate and propionate are available for such service. Acetate and ethyl cellulose are not recommended for outdoor use. Most cellulosic formulations are available in 94HB flammability classification. Also available are formulations that can be used in contact with food.

Applications: Acetate applications include extruded and cast film and sheet for packaging and thermoforming, and extruded rod for tool and appliance handles and machine parts, eyeglass frames, pen barrels and caps, and quality toys.

Propionate molding applications include automotive and marine steering wheels, fuel-filter bowls, toothbrush handles, containers for cosmetics, face shields, safety goggles, and machine components that require transparency and toughness. Transparent sheets are used in heavy-duty blister packaging and transparent packaging for food contact (FDA-accepted formulations) applications.

Butyrate is used for data-processor and cash-register keys, transparent dial covers, tool handles, and covers for instrument-panel lights. Opaque formulations are used for pens, switch covers, and knobs. Typical applications for weathering-grade formulations are outdoor signs, window-well covers, skylights, and sprinklers. Extruded sheet is used for windshields, industrial shields, and thermoformed signs. Extruded-profile applications include table edging, tool handles, and trim strips.

Ethyl cellulose is used in helmets, gears, rollers, slides, flashlight housings, and tool handles. Military applications utilize its toughness and its resistance to nitroglycerine and black powder.

Engineering films

Specific properties that separate engineering films from their commodity counterparts include greater tensile and impact strength; improved moisture and gas barrier characteristics; good heat resistance and weatherability; better bonding and lamination; and improved electrical ratings. One or more of these properties can be obtained by choosing from a number of different polymer films.

Several melt-processible engineering thermoplastic films such as **oriented polyester**, **oriented nylon**, and **unoriented nylon**, exhibit high strength especially at high temperatures. In addition, they provide toughness at low temperatures, stiffness and abrasion resistance, and good chemical resistance. Polyester film is made from the PET polymer, principally by Du Pont (Mylar) and ICI (Melinex). The monomer is polymerized, extruded, cast into a web, and biaxially oriented, forming a drawn polyester film.

Oriented polypropylene, a thermoplastic with low specific gravity, has excellent resistance, relatively high melting point, and good strength. **Polycarbonate** film is specified for its toughness, clarity, and high heat-deflection temperature.

Polyimides, both thermoplastics and thermosets, retain their principal properties over a wide temperature range. Polyimide films are available from ICI (Upilex) and Du Pont (Kapton). They have useful mechanical properties, even at cryogenic temperatures. At −453°F, the film can be bent around a ½-in. mandrel without breaking and, at 932°F, its tensile strength is 4,500 psi. Room-temperature mechanical properties are comparable to those of polyester film.

To minimize transmission of moisture vapors, **fluoropolymers** are the best choice. This family of materials has a general paraffinic structure with

Comparing performance film properties

ASTM test	Property	Nylon 6 Monaxial	Nylon 6 Biaxial	Polyester (PET)	Fluoropolymers (CTFE)	Fluoropolymers (ECTFE)	Fluoropolymers (FEP)	Polyimide
D882	**Tensile strength** (psi)	50,000-MD 10,000-TD	32,000-35,500	20,000-35,000	4,000-11,000	8,000-10,000	2,500-3,000	8,200-35,000
D882	**Elongation** (%)	60-MD 450-TD	100-200	60-165	50-300	150-250	300	95
D1922	**Tear strength** (Elmendorf) (g/mil)	1,300-MD 650-TD	16-28	50-300	12-40	900-1,000	125	—
E96	**Moisture vapor transmission rate** (g/mil/100 in.^{2}/24 h at 37.8°C)	15	11-12	1.0-1.3	0.30	0.60	0.40	5.4
D1434	**Gas permeability-O_2** (cc-mil/100 in.^{2}/24h at 25°C)	2.0	1.2-1.4	3-6	12	25	750	25
	Chemical resistance	Good	Good	Good	Excellent	Good	Good	Good
D150	**Dielectric constant** (1kHz)	3.7	—	3.2	2.7	2.6	2.0-2.5	3.4
D150	**Dissipation factor** (1 kHz)	0.016	—	0.005	0.0245	0.002	0.0002	0.0014
D149	**Dielectric strength** (V/mil)	—	—	7,500	—	5,000-6,000	6,500	7,800

MD = Machine direction TD = Transverse direction some or all of the hydrogen atoms replaced by fluorine.

Polyetheretherketone (PEEK), a high-performance thermoplastic, offers outstanding thermal properties as well as resistance to many solvents and proprietary fluids. This film can be used for interbonding or cladding in PEEK structural components. Thermoplastic and thermoset **acrylics** are noted for exceptional clarity and weatherability, and also offer favorable stiffness, density, chemical resistance, and toughness.

Film produced from PEEK resins (ICI's Stabar) can be laminated to itself or to other substrates. Bond strength depends on surface preparation and adhesive type. The film is available in a transparent, thermoformable grade and in a higher-temperature, heat-stabilized version, which is more crystalline and less transparent (also thermoformable).

Plastic film can be manufactured from almost any resin, but not every resin produces an engineering film. Generally, a resin-based film's properties are related to the chemistry of the basic polymer; however, properties may be further affected by subsequent processing techniques. Manufacturers can choose from, and end users can specify, a range of process treatments that significantly enhance heat stability, mechanical properties, electrical characteristics, barrier properties, and bondability.

Coatings are typically applied by emulsion, solvent, and dry methods. Results vary according to the formula used: PVDC coatings improve barrier properties; polyurethane improves abrasion resistance; and aluminum coatings alter electrical characteristics.

Some processors have developed proprietary antistatic coatings that are cured by electron-beam radiation. Metal coatings produce conductive capabilities and also enhance barrier properties. Often, metallization is used to improve moisture-barrier properties for biaxially oriented nylon and polypropylene.

Polycarbonate	Polypropylene	Acrylic (standard)
8,400-11,000	7,500-40,000	8,200-8,800
40-105	35-475	4-12
20-25	3-10	—
11	0.25-0.40	1.3
300	160	—
Good	Good	Good
2.99	2.2	3.5-4.0
0.0015	0.0002-0.002	0.04
6,300	8,000	—

Surface treatment, which removes low-molecular-weight residue, improves adhesion and appearance. Several methods may be used. Corona discharge techniques position the film between an electrically grounded roller and a high-voltage electrode. A continuous-arc discharge (corona) is generated to clean and activate the film surface.

In gas-plasma surface treatments, film is placed in a reaction chamber. After evacuation, the chamber is charged with oxygen, argon, helium, or nitrogen while a radio-frequency field ionizes the gas. A resultant glow discharge creates free radicals on the surface, improving adhesion.

Film can be passed over a bank of flame jets to activate the surface and burn off contaminants. Other surface preparation techniques include polishing and embossing by roller.

Additionally, performance films combine base-resin properties with advantages unique to the film form. A film may be selected both for its dielectric properties and for its usefulness as a bonding material, thus serving two needs. Fabrication techniques such as coextrusion and lamination produce a film with the best properties of two or more individual films — strength combined with barrier properties and optical clarity, for example.

The use of various additives, modifiers, and pigments comprise another method for improving film performance. These are blended into the resin melt or introduced at the extruder, supplying the end film with specific characteristics. UV and heat stabilizers are among the most useful additives.

Applications for engineering films span a broad spectrum of industrial uses. Film-based products appear in photographic, business graphic, reprographic, and electronic imaging systems. Magnetic-media manufacturers also rely on high-quality flexible films to produce their information-handling products. Packaging end users receive product protection, extended shelf life, and visual impact from a variety of films. In the electronics industry, films are used to construct components such as membrane switches.

Transparent PEEK film is used for a missile nose cone because of its microwave transmittance and resistance to rain erosion. Potential applications for the crystalline grade include helicopter-rotor blade cladding, fine-line microwave circuits, and aircraft interior panels.

Epoxy

Epoxy polymers are cured to form thermoset resins by either of two methods: homopolymerization of epoxy groups with themselves, or reaction with curing agents such as anhydrides, amines, and novolacs. Because the curing agent contributes significantly to the cured properties of the resin, this is called an addition reaction. Shrinkage during polymerization of epoxy resins is extremely low.

The most widely used epoxy resins are based on the reaction of epichlorohydrin with bisphenol-A. The reaction ratios of these two constituents can be varied to produce products ranging from low-viscosity liquids to high-molecular-weight solids.

The novolacs are another important class of epoxy resins, particularly the ECNs (epoxy cresol novolacs) and EPNs (epoxy phenol novolacs). These polyfunctional resins offer higher thermal properties and improved chemical resistance over bis-A derivatives. The cycloaliphatics comprise a third group of epoxy resins that are particularly important for applications requiring resistance to arc tracking and weathering. A fourth class of epoxy resins is based on the epoxidation of aromatic amines. These resins have good mechanical properties and high thermal capabilities and fatigue resistance.

Properties: Epoxies have excellent electrical, thermal, and chemical resistance. Their strength can be further increased with fibrous reinforcement or mineral fillers. The variety of combinations of epoxy resins and reinforcements provides a wide latitude in properties obtainable in molded parts.

Molded epoxy parts are hard, rigid, relatively brittle, and have excellent dimensional stability over a broad temperature range. Some fiber-reinforced formulations can withstand service temperatures above 500°F for brief periods. Their excellent electrical properties, in combination with high mechanical strength, qualify them for electrostructural applications. Resins based on bisphenol-A are adequate for most services. However, cycloaliphatics are recommended for parts subjected to arcing conditions or those requiring outdoor weatherability.

Excellent adhesion in structural ap-

SOLUTIONS

The list of applications for high-performance plastics keeps piling up.

Fortron® PPS and Vectra® LCP solve the problems metal can't.

Until now, getting the strength of metal meant putting up with its weaknesses: weight, corrosion, design limitations, and expensive extra assembly steps.

At Hoechst Celanese, we have engineered materials specifically designed to be strong where metal is weak. Even at high temperatures. Even in the most complex parts. Even in hostile environments.

Fortron® PPS and Vectra® LCP can improve your product's quality and reliability, reduce total part costs — even trim weight by up to 80%.

Blower housing for forced hot air furnace uses Fortron® PPS as a sheet metal replacement for improved efficiency and resistance to corrosive by-products of combustion.

First, we have Fortron polyphenylene sulfide, with chemical resistance that puts metal on the scrap heap. No known solvent dissolves it at temperatures below 400° F. So chemical pumps, valves and other parts can be made lighter, simpler and more durable. What's more, in places like engines and furnaces, Fortron is comfortable up to 500° F.

Next, there's Vectra, the world's leading liquid crystal polymer. In complex parts with thin walls, Vectra will give you remarkably high strength and stiffness. And consider that Vectra can achieve tolerances equal to machined die-cast metals — without any machining. It can also be easily molded into shapes impossible with metals. All of which makes Vectra perfect for everything from intricate watch gears to electrical connectors to multiple-use, sterilizable health care devices.

As you can see, metal is no longer king of the hill. There are superior alternatives, and the specialists at Hoechst Celanese can put them cost-effectively to work for you …from initial design guidance to CAD/CAM simulation to prototyping. For application guidance, call John Dole at (201) 635-4139 today. For literature, circle the Reader Service Number.

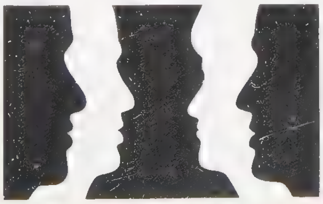
Ultrasonic dental cleaner made with Vectra® LCP can withstand repeated radiation, chemical and steam sterilization, and cost-effectively replaces traditional metals.

Advanced Materials Group
Hoechst Celanese Corporation

Hoechst Celanese

Hoechst

The Hoechst name and logo are registered trademarks of Hoechst AG
® Registered trademark of Hoechst Celanese Corporation
© 1991 Hoechst Celanese Corporation



PERSON TO PERSON

Circle 586

Epoxy molding and casting resins

		MOLDING COMPOUNDS		CASTING RESINS		
				Bisphenol A		
ASTM test	Property	Glass-fiber filler	Mineral filler	No filler	Silica filler	Cycloallphatic
	PHYSICAL					
D792	**Specific gravity**	1.6-2.0	1.6-2.0	1.11-1.40	1.6-2.0	1.16-1.21
D792	**Specific volume** (in.^{3}/lb)	15.4-14.0	14.2-13.4	24.9-20.0	17.3-13.9	—
D570	**Water absorption**, 24 h, ⅛-in. thk (%)	0.05-0.20	0.04	0.08-0.15	0.04-0.10	0.08-0.15
	MECHANICAL					
D638	**Tensile strength** (psi)	10,000-20,000	5,000-10,000	4,000-13,000	7,000-13,000	10,000-20,000
D638	**Elongation** (%)	4	—	3-6	1-3	2-10
D638	**Tensile modulus** (10^5 psi)	30.4	—	3.5	—	5-9
D790	**Flexural strength** (psi)	10,000-60,000	8,000-15,000	13,300-21,000	8,000-14,000	15,000-32,000
D256	**Impact strength**, Izod (ft-lb/in. of notch)	2-30	0.3-0.4	0.2-1.0	0.3-0.45	0.2-1.0
D785	**Hardness**, Rockwell M	100-110	110-110	80-110	85-120	85-120
	THERMAL					
C177	**Thermal conductivity** (10^{-4} cal-cm/sec-cm^2-°C)	4-10	4-30	4.0-5.0	10-20	—
D696	**Coef of thermal expansion** (10^{-5} in./in.-°C)	1.1-3.5	2.0-5.0	4.5-6.0	2.0-4.0	—
D648	**Deflection temperature** (°F) At 264 psi	250-500	250-500	115-550	160-550	200-450
	ELECTRICAL					
D149	**Dielectric strength** (V/mil) Short time, ⅛-in. thk	300-400	300-400	300-500	400-550	420-440
D150	**Dielectric constant** At 1 kHz	3.5-5.0	3.5-5.0	3.5-4.5	3.2-4.0	3.9-4.5
D150	**Dissipation factor** At 1 kHz	0.01	0.01	0.002-0.02	0.008-0.03	—
D257	**Volume resistivity** (ohm-cm) At 73° F, 50% RH	$>10^{14}$	$>10^{14}$	10^{12}-10^{17}	10^{13}-10^{16}	10^{15}
D495	**Arc resistance** (s)	120-180	150-190	45-120	150-300	150-180

plications is another outstanding property of epoxy systems. Epoxy adhesives for bonding many dissimilar materials can be supplied either as one or two-part systems. One-part systems require heat for curing; two-part systems usually cure at room temperature, but properties are improved when the materials are heat cured. Some epoxy adhesive systems can withstand temperatures to 450°F, although properties at such temperatures are considerably lower than at room temperature.

Applications: Epoxy resin systems are used with various reinforcements: glass, graphite and aramid fibers, asbestos, cotton, and metal foils. Epoxy laminates are important because of their excellent electrical properties over a wide temperature range, as well as their dimensional stability and chemical resistance. The amine-based resins are used in conjunction with graphite fiber to make structural composites for commercial and military aircraft and components for space equipment. These composites offer significant advantages over metals in the areas of weight savings and corrosion resistance. Printed-circuit boards, consisting of a glass-fabric-reinforced flame-retardant epoxy resin are another major use.

Filled and unfilled liquid systems are used for potting and encapsulating electrical/electronic components ranging from semiconductor devices and miniature coils and switches to large motors and generators. The epoxy resins provide excellent adhesion, and low shrinkage (volume shrinkage is only 2 to 3%) needed for such applications. The compounds cure in 1 to 4 h, and they do not outgas during the cure or in service. The casting cycle can be significantly accelerated by using one of the newer processes: liquid injection molding or pressure gelation. The latter method can reduce the molding cycle of a 15-lb casting from 4 h to 10 min. Applications being evaluated for pressure-gelation casting include high-voltage electrical components and pump and valve housings.

Another important use for epoxy resins is in coatings, both as liquids and powders. These finishes have excellent flexibility, impact and abrasion resistance, and adhesion to most substrates. They can be formulated to resist many industrial chemicals and other corrosive materials. Epoxy coatings are typically used as automotive and appliance primers, in industrial maintenance paints, marine finishes, pipe coatings, and decorative topcoats for various products.

Epoxy resins are also furnished as molding powders, usually incorporating glass or mineral-fiber reinforcement. These compounds can be molded by conventional thermoset methods. The outstanding electrical and thermal properties qualify the epoxies for industrial switchgear applications and for encapsulating semiconductor devices.

Fluoroplastics

The family of thermoplastics are extremely inert, paraffinic thermoplastic polymers that have some or all of the hydrogen replaced with fluorine. The family of materials includes polytetrafluoroethylene (PTFE, commonly called TFE), fluorinated ethylene propylene (FEP), perfluoroalkoxy (PFA), polychlorotrifluoroethylene (CTFE), poly (ethylene-chlorotrifluoroethylene (ECTFE) copolymer, ethylene tetrafluoroethylene (ETFE), polyvinylidene fluoride (PVDF), polyvinylfluoride (PVF), and copolymers of halogenated and fluorinated ethylenes.

PTFE, FEP, and PFA: Their high

melt viscosity prevents PTFE resins from being processed by conventional extrusion and molding techniques. Instead, molding resins are processed by press-and-sinter methods similar to those of powder metallurgy or by lubricated extrusion and sintering. All other fluoroplastics are melt processible by techniques commonly used with other thermoplastics.

PTFE resins are opaque, crystalline, and malleable. When heated above 648°F, however, they are transparent, amorphous, relatively intractable, and they fracture if severely deformed. They return to their original state when cooled.

FEP resins offer nearly all of the desirable properties of PTFE, except thermal stability. Maximum recommended service temperature for these resins is lower by about 100°F. PFA fluorocarbon resins are easier to process than FEP and have higher mechanical properties at elevated temperatures. Service temperature capabilities are the same as those of PTFE.

PTFE resins are supplied as granular molding powders for compression molding or ram extrusion, as powders for lubricated extrusion, and as aqueous dispersions for dip coating and impregnating. FEP and PFA resins are supplied in pellet form for melt extrusion and molding. FEP resin is also available as an aqueous dispersion.

Properties: Outstanding characteristics of the fluoroplastics are chemical inertness, high and low-temperature stability, excellent electrical properties, and low friction. However, the resins are fairly soft and resistance to wear and creep is low. These characteristics are improved by compounding the resins with inorganic fibers or particulate materials. For example, the poor wear resistance of PTFE as a bearing material is overcome by adding glass fiber, carbon, bronze, or metallic oxide. Wear resistance is improved by as much as 1,000 times, and the friction coefficient increases only slightly. As a result, the wear resistance of filled PTFE is superior, in its operating range, to that of any other plastic bearing material and is equalled only by some forms of carbon.

The static coefficient of friction for PTFE resins decreases with increasing load. Thus, PTFE bearing surfaces do not seize, even under extremely high loads. Sliding speed has a marked effect on friction characteristics of unreinforced PTFE resins; temperature has very little effect.

PTFE resins have an unusual thermal expansion characteristic. A transition at 65°F produces a volume increase of over 1%. Thus, a machined part, produced within tolerances at a temperature on either side of this transition zone, will change dimensionally if heated or cooled through the zone.

Electrical properties of PTFE, FEP, and FPA are excellent, and they remain stable over a wide range of frequency and environmental conditions. Dielectric constant, for example, is 2.1 from 60 to 10^9 Hz. Heat-aging tests at 572°F for six months show no change in this value. Dissipation factor of PTFE remains below 0.0003 up to 10^8 Hz. The factor for FEP and PFA resins is below 0.001 over the same range. Dielectric strength and surface arc resistance of fluorocarbon resins are high and do not vary with temperature or thermal aging.

Applications: PTFE resin applications can be classified in five categories: 1. Fluid conveying systems — gaskets, molded packings and seals, piston rings, and bellows. 2. Static and dynamic load supports — bearings, ball and roller-bearing components, and sliding bearing pads. 3. Release surfaces — sheet for preventing adhesion, pressure-sensitive tapes, and heat-shrinkable roll covers. 4. Electrical and electronic — insulation for coaxial cable, fixture and motor lead wire, hookup and panel wiring, industrial signal and control cable, and for standoff and feedthrough components. 5. Thermal system components — ablative shields.

FEP resin applications include wire and cable insulation for computer and electronic systems, telephone and alarm systems, and business-machine interconnects, FEP resin is also supplied as extruded sheet and film for release surfaces, roll covers, linings for chemical-processing tanks, and piping. A concentrate is available for Freon-blown-foam wire coating.

PFA resins are used for high-temperature wire and cable insulation, heat-shrinkable tubing and roll covers, chemical-resistant linings for process-equipment components, and in semiconductor processing equipment.

Materials do not adhere readily to the slippery surface of FEP, PFA, and PTFE parts. Surfaces can be chemically etched, however, to permit bonding with adhesives. Thus, low-friction surfaces of fluorocarbon tape or film can be bonded to steel, aluminum, rubber, or other materials. FEP and PFA parts can be heat sealed to themselves, to PTFE parts, or to metals at low pressure and temperatures above 590°F.

CTFE: Sensitivity to processing conditions is greater in CTFE resins than in most polymers. Molding and extruding operations require accurate temperature control, flow channel streamlining, and high pressure because of the high melt viscosity of these materials. With too little heat, the plastic is unworkable; too much heat degrades the polymer. Degradation begins at about 525°F. Because of the lower temperatures involved in compression molding, this process produces CTFE parts with the best properties.

Thin parts such as films and coil forms must be made from partially degraded resin. Degree of degradation is directly related to the reduction in viscosity necessary to process a part. Although normal, partial degradation does not greatly affect properties, seriously degraded CTFE becomes highly crystalline, and physical properties are reduced. Extended usage above 250°F also increases crystallinity.

CTFE plastic is often compounded with various fillers. When plasticized with low-molecular-weight CTFE oils, it becomes a soft, extensible, easily shaped material. Filled with glass fiber, CTFE is harder, more brittle, and has better high-temperature properties.

Properties: CTFE plastics are characterized by chemical inertness, thermal stability, and good electrical properties, and are usable from 400 to −400°F. Nothing adheres readily to these materials, and they absorb practically no moisture. CTFE components do not carbonize or support combustion. Up to thicknesses of about ⅛ in., CTFE plastics can be made optically clear. Ultraviolet absorption is very low, which contributes to its good weatherability.

Compared with PTFE, FEP, and PFA fluorocarbon resins, CTFE materials are harder, more resistant to creep, and less permeable; they have lower melting points, higher coefficients of friction, and are less resistant to swelling by solvents than the other fluorocarbons.

Tensile strength of CTFE moldings is moderate, compressive strength is high, and the material has good resistance to abrasion and cold flow. CTFE plastic has the lowest permeability to moisture vapor of any plastic. It is also impermeable to many liquids and gases, particularly in thin sections.

Applications: Molded and extruded CTFE resin applications include components for handling and containing corrosive liquids (diaphragms, valves, sight glasses); seals, gaskets, O-rings, valve seats, and packings for liquid-oxygen and hydro-

Fluoroplastics

ASTM or UL test	Property	PTFE	FEP	PFA	PVDF	CTFE*	Modified ETFE
	PHYSICAL						
D792	**Specific gravity**	2.13-2.24	2.12-2.17	2.12-2.17	1.75-1.78	2.13	1.70
D792	**Specific volume** (in.^{3}/lb)	13-12.3	13.0-12.7	13.0-12.7	15.7-15.6	—	16.3
D570	**Water absorption**, 24 h, ⅛-in. thk (%)	<0.01	<0.01	0.03	0.04	0.01	<0.03
	MECHANICAL						
D638	**Tensile strength** (psi)	3,350	3,000	4,000	5,200-7,400	5,430	6,500
D638	**Elongation** (%)	300	300	300	100-300	125	275
D638	**Tensile modulus** (10^5 psi)	0.5	—	—	1.6	1.86	1.2
D790	**Flexural strength** (psi)	No break	No break	No break	No break	10,700	No break
D790	**Flexural modulus** (10^5 psi)	0.5-0.9	0.95	0.95	2.0	2.54	2.0
D256	**Impact strength**, Izod (ft-lb/in. of notch)	3.5	No break	No break	3-4	3.1	No break
D785	**Hardness**, Rockwell	—	—	—	—	S 85	R50
	Shore D	50-65	55	60	80	79	—
	THERMAL						
C177	**Thermal conductivity** (Btu-in./h-ft^2-°F)	1.7	1.4	1.8	0.7-0.9	1.83	1.65
D696	**Coef of thermal expansion** (10^{-5} in./in.-°F)	5.5-8.4	4.6-5.8	6.7	8.0-8.5	4.8, 15†	5.2
D648	**Deflection temperature** (°F)						
	At 264 psi	132	124	118	195	167	165
	At 66 psi	250	158	164	300	265	220
UL 94	**Flammability rating**	V-0	V-0	V-0	V-0	V-0	V-0
	ELECTRICAL						
D149	**Dielectric strength** (V/mil)						
	Short time, ⅛-in. thk	500-600	500-600	500-600	260	490	400-500
D150	**Dielectric constant**						
	At 1 kHz	2.1	2.1	2.1	7.5	2.45	2.6
D150	**Dissipation factor**						
	At 1 kHz	0.00005	0.00005	0.0003	0.019	0.0247	0.0008
D257	**Volume resistivity** (ohm-cm)						
	At 73° F, 50% RH	$>10^{18}$	$>10^{18}$	$>10^{18}$	2×10^{14}	2.5×10^{16}	10^{16}
D495	**Arc resistance** (s)	>300	>180	>180	50-70	360	75
	OPTICAL						
D542	**Refractive Index**	1.350	1.344	1.350	1.42	1.435	1.403
D1003	**Transmittance** (%)						
	1-mil film	—	>95	>95	>90	>90	—
	FRICTIONAL						
—	**Coefficient of friction** Against steel (100 psi, 10 fpm)	0.050	0.330	0.214	0.14	—	0.400

*Crystalline compound. †Below and above 135°F.

gen equipment; and flexible-circuit laminations, wire insulation, jacketed cable, coil bobbins, and other electrical components. CTFE materials are FDA-approved for use in food-handling equipment. Thin, optically clear CTFE moldings are used for infrared windows in missiles, radome covers, oil-reservoir covers, and gage faces.

PVDF: Polyvinylidene fluoride, the toughest of the fluoroplastic resins, is available as pellets for extrusion and molding and as powders and dispersions for corrosion-resistant coatings. This high-molecular-weight homopolymer has excellent resistance to stress fatigue, abrasion, and to cold flow. Although insulating properties and chemical inertness of PVDF are not as good as those of the fully fluorinated polymers. PTFE and FEP, the balance of properties available in PVDF qualifies this resin for many engineering applications. It can be used over the temperature range from −100 to 300°F and has excellent resistance to abrasion.

PVDF can be used with halogens, acids, bases, and strong oxidizing agents, but it is not recommended for use in contact with ketones, esters, amines, and some organic acids. Oxygen index is 44.

Although electrical properties of PVDF are not as good as those of other fluoroplastics, it is widely used to insulate wire and cable in computer and other electrical and electronic equipment. Heat-shrinkable tubing of PVDF is used as a protective cover on resistors and diodes, as an encapsulant over soldered joints.

Valves, piping, and other solid and lined components are typical applications of PVDF in chemical-processing equipment. It is the only fluoroplastic available in rigid pipe form. Woven cloth made from PVDF monofilament is used for chemical filtration applications.

A significant application area for PVDF materials is as a protective coating for metal panels used in outdoor service. Blended with pigments, the resin is applied, usually by coil-coating equipment, to aluminum or galvanized steel. The coil is subsequently formed into panels for industrial and commercial buildings.

A recently developed capability of

PVDF film is based on the unique piezoelectric characteristics of the film in its so-called beta phase. Beta-phase PVDF is produced from ultrapure film by stretching it as it emerges from the extruder. Both surfaces are then metallized, and the material is subjected to a high voltage to polarize the atomic structure.

When compressed or stretched, polarized PVDF generates a voltage from one metallized surface to the other, proportional to the induced strain. Infrared light on one of the surfaces has the same effect. Conversely, a voltage applied between metallized surfaces expands or contracts the material, depending on the polarity of the voltage.

PTFE and ECTFE: One of the advantages of the copolymers of ethylene and TFE — called modified ETFE — and of ethylene and CTFE — called ECTFE— compared with PTFE and CTFE, is their ease of processing. Unlike their predecessors, they can be processed by conventional thermoplastic techniques. Various grades can be made into film or sheet, into a monofilament, or used as a powder coating; all grades can be heat sealed or welded.

Although these resins have lower heat resistance than PTFE or CTFE, they offer a combination of properties and processibility that is unattainable in the predecessor resins. Maximum service temperature for no-load applications is in the range of 300 to 390°F for ETFE and ECTFE, compared with 390° for CTFE and 550° for PTFE. Glass reinforcement increases these values by 50°F.

Both tensile strength and toughness of these resins are higher than those of the other fluoropolymers; they are rated "no break" in notched Izod tests. Modulus of ECTFE is higher than that of ETFE up to about 100°C; above 150°C, ETFE has a higher modulus. Deflection temperature of both resins is similar, with ECTFE slightly higher (240°F, compared with 220°F, at 66 psi, and 170°F compared with 160°F at 264 psi). Hardness of ETFE is Rockwell R50; that of ECTFE is R93.

Limiting Oxygen Index of ETFE is 31; that of ETCFE is 60. (LOIs of PTFE, FEP, and CTFE are over 95.)

As with other fluoroplastics, these resins are compatible with most chemicals, even at high temperatures. ETFE is not attacked by most solvents to temperatures as high as 390°F. ECTFE is similar to 250°F, but is attacked by chlorinated solvents at higher temperatures. ETFE has better chemical stress-crack resistance.

Applications for these resins include wire and cable insulation, chemical-resistant linings and molded parts, laboratory ware, and molded electrostructural parts.

Representative commercial fluoroplastics:
PTFE, Du Pont (Teflon TFE), Allied-Signal (Halon, TFE), ICI Americas (Fluon)
FEP, Du Pont (Teflon FEP)
PFA, Du Pont (Teflon PFA)
CTFE, 3M (Kel-F), Allied-Signal (Plaskon CTFE)
PVDF, Pennwalt (Kynar), Atochem (Foraflon)
PVF, Du Pont (Tedlar)
ETFE, Du Pont (Tefzel)
ECTFE, Allied-Signal (Halar)

Liquid-crystal polymers

Liquid-crystal polymers are a unique class of wholly aromatic polyester polymers that provide previously unavailable high-performance properties. Particularly outstanding is their heat-deflection temperature at 264 psi of 460 to 606°F. Structure of the LCPs consists of densely packed fibrous polymer "chains" that provide self-reinforcement almost to the melting point.

Before the commercial introduction of LCP resins in 1984, liquid-crystal polymers could not be injection molded. Today's resin can be melt processed on conventional equipment into thin-wall as well as heavy-wall components at fast speeds with excellent replication of mold details and efficient use of regrind.

Commercial melt-processible resins now available are Xydar formulations (biphenol based) from Amoco Performance Products and Vectra resins (naphthaline based) from Hoechst Celanese Corp. Molding these high-temperature resins requires heated tools and equipment capable of producing melt temperatures of 545 to 620°F for Vectra resins and 700 to 850°F for Xydar materials.

Properties: LCP resins are characterized by outstanding strength at extreme temperatures; excellent mechan-

Liquid crystal polymers

ASTM or UL test	Property	Glass filled*	Glass/mineral filled*	Mineral filled*	Unmodified and filled resins†
	PHYSICAL				
D792	**Specific gravity**	1.70	1.79	1.86	1.4-1.9
D570	**Water absorption**	<0.01	0.02	<0.01	0.02-0.04
	MECHANICAL				
D638	**Tensile strength** (psi)	16,000	12,500	11,000	20,000-35,000
D638	**Elongation** (%)	2	2.0	1.3	1.2-6.9
D638	**Tensile modulus** (10^5 psi)				
	At 73°F	18	17.5	18.5	1.4-5.5
	At 450°F	11.4	11.3	8	—
	At 575°F	8.73	8.5	7	—
	At −65°F	—	—	—	—
D790	**Flexural strength** (psi)	18,000	19,000	15,000	22,000-43,000
D790	**Flexural modulus** (10^5 psi)				
	At 73°F	16	18.6	16	1.3-5.0
	At 450°F	6.5	8.7	6	—
	At 575°F	4.9	4.5	2	—
	At −65°F	—	—	—	—
D256	**Impact strength, Izod** (ft-lb/in. of notch)	1.9	1.2	1.1	1-10
	THERMAL				
E831	**Coef of thermal expansion** (10^{-5} in./in.-°C)				0-2.5 (flow)
	At 20 to 300°C	0.83	0.89	2.1	2.5-5.0 (trans)
D648	**Deflection temperature** (°F)				
	At 264 psi	592	606	563	350-460
UL94	**Flammability rating,** 1/16 in.	V-0@1/32 in.	V-0	V-0	V-0
	UL continuous (electrical) operating temperature (°C)	220	—	240	—
D2863	**Oxygen index** (%)	45	44	46	35-50
	ELECTRICAL				
D149	**Dielectric strength** (V/mil)	510	470	955	790-1,100
D150	**Dielectric constant**				
	At 10^2 Hz	4.59	4.91	4.58	2.6-3.3
D150	**Dissipation factor**				
	At 10^2 Hz	0.008	0.009	0.016	0.003-0.004
D257	**Volume resistivity** (ohm-cm)	4.0×10^{15}	4.0×10^{15}	4.4×10^{15}	10^{15}-10^{16}
D495	**Arc resistance** (s)	192	193	244	63-181

*Representative Xydar grades †Property ranges for several Vectra resins ical-property retention after exposure to weathering and radiation; good dielectric strength, arc resistance, and dimensional stability; low coefficient of thermal expansion; excellent flame retardance; and easy processibility. UL continuous-use rating for electrical properties is as high as 240°C and, for mechanical properties, 220°C. The high heat-deflection value of biphenol-based resins permits molded parts to be exposed to intermittent temperatures as high as 315°C without affecting properties. Resistance to high-temperature flexural creep is excellent, as are fracture-toughness characteristics.

LCPs are exceptionally inert. They resist stress cracking in the presence of most chemicals at elevated temperatures, including aromatic or halogenated hydrocarbons, strong acids, bases, ketones, and other aggressive industrial substances. Hydrolytic stability in boiling water is excellent. Environments that deteriorate the polymers are high-temperature steam, concentrated sulfuric acid, and boiling caustic materials.

Oxygen index of LCP resins ranges from 35 to 50%. When exposed to open flame, the material forms an intumescent char that prevents dripping and results in extremely low generation of smoke containing no toxic by-products. The resin has UL94V-0 and 5V flammability ratings at 1/16 in. and an NBS smoke-chamber rating (NBS-D_s-4) of 3 to 5. Compounds are unaffected by high doses of ionizing or cobalt 60 radiation (up to 10 billion rads), withstand high levels of ultraviolet radiation, and are transparent to microwaves and other radiation of similar wavelength.

Easy processibility of the resins is attributed to its liquid-crystal molecular structure, which provides high melt flow and fast setup in molded parts. However, molded parts are highly anisotropic, and knit lines are much weaker than other areas. Properties are not affected by minor variations in processing conditions, and no postcuring is required.

Applications: Metal and ceramic replacement in applications that require resistance to high temperature, chemicals, mechanical stress, and creep is where LCP resins are expected to be used. Typical parts include electrical-electronic components such as connectors, sockets, and pin-grid arrays exposed to high-temperature manufacturing or service conditions; automotive and aerospace parts requiring high-temperature resistance and flame retardance; and chemical-process components — for example, mass-transfer tower packing elements — requiring resistance to aggressive substances at high temperatures.

Nylon

Nylons (polyamides), the first of the thermoplastic engineering resins, were developed originally as high-strength textile fibers. These semicrystalline plastics are available in compositions for molding and extruding, for solution and fluidized-bed coatings, and for casting.

Nylon 6/6 is the most widely used of the nylon plastics because of its overall balance of properties. The second most widely used of the nylon family is nylon 6. Properties of nylon 6 are similar to those of 6/6, but it absorbs moisture more rapidly and its melting point is 70°F lower, which limits its use to moderate temperature applications.

Nylon 6/12 absorbs less moisture and, therefore, maintains both mechanical and electrical properties better in high-humidity environments. But the reduced moisture sensitivity is accompanied by lower strength, lower stiffness, lower use temperatures, and higher cost.

Nylons 11 and 12 have lower moisture absorption and combined with superior resistance to fuels, hydraulic oils, and most automotive fluids. The melting points of nylon 11 and 12 (355 to 365°F) are the lowest of the commercial polyamides. These two polyamides are often combined with plasticizers to generate a flexible, tough material suitable for tubing extrusion. Recently nylon 12/12 has been introduced with a slightly higher use temperature while maintaining good fuel resistance.

Nylon 4/6 is the latest version of the short repeat-unit polyamides. Its melting point of 565°F is 54°F above that for nylon 6/6 and is the highest in the polyamide family. The inherent molecular symmetry of nylon 4/6 results in self-nucleation, rapid crystal growth and, thus, a higher level of crystallinity. This higher level of crystallinity leads to faster set up and, hence, faster injection-molding cycles, up to 30% faster than for 6/6. Nylon 4/6 absorbs more water than nylon; however, its dimensional stability is similar to nylon 6/6 due to its high crystallinity.

Higher crystallinity has a major effect on nearly all properties leading to higher strength, higher stiffness, high heat-deflection temperature (HDT), high fatigue resistance, high wear resistance, and high creep resistance. Semicrystalline polymers maintain useful properties above the glass transition in contrast to amorphous polymers which transform into a viscous mass. Nylon 4/6, with its unusually high crystallinity, maintains a higher level of performance at elevated temperatures. The HDT for reinforced nylon 4/6 is 545°C.

Nylon resin is available in a wide range of reinforcement levels, filler types, toughening agents, stabilizers and flame-retardant additives. Newer flame retardants can provide good flammability ratings (UL94V-0) while maintaining acceptable electrical properties.

Toughening technology has reduced notch sensitivity providing notched Izod values over 15 ft-lb/in. Some of these impact modifiers also provide Gardner drop-weight impact strengths in excess of 480 in.-lb (1/8-in.-thick disks).

Nylon is available in several physical forms. Nylon 6 and certain block copolymers can be cast as monomer into large shapes that polymerize into solids at room temperature. Parts several inches thick and weighing several hundred pounds can be cast. Axially symmetric shapes can be extruded. Nylon rod, and plate and tubular bar are available as stock shapes. Tubing and profile extrusions are available as custom shapes.

Properties: Property comparisons among commercial grades of nylon vary widely because so many formulations are available. In general, however, nylons have excellent fatigue resistance, low coefficient of friction, good toughness (depending on degree of crystallinity), and they resist a wide spectrum of fuels, oils, and chemicals. They are inert to biological attack, and have adequate electrical properties for most voltages and frequencies.

The crystalline structure of nylons, which can be controlled to some degree in processing, affects stiffness, strength, and heat resistance. Low crystallinity imparts greater toughness, elongation, and impact resistance, but at the sacrifice of tensile strength and stiffness.

Nylons 6/6 and 4/6 have the lowest permeability of the nylons by gasoline, mineral oil, and fluorocarbon refrigerants. Nylon 6/12 is used where lower moisture absorption (and better dimensional stability) are needed.

All nylons absorb moisture from the environment. Moisture absorption leads to dimensional and property changes dependent upon the equilibrium level absorbed. At elevated temperatures, the moisture equilibrium level decreased above 190°F, nylon begins to dry out by a combination of internal diffusion and surface

Nylons (dry as molded)

ASTM or UL test	Property	Type					
		4/6	6/6	6	6/12	11	Cast 6
	PHYSICAL						
D792	**Specific gravity**	1.13	1.14	1.14	1.07	1.04	1.15
	Specific volume (cu. in/lb)	23.5	24.3	24.3	25.9	26.6	24.1
D570	**Water absorption,** 24 hr 1/8 in. thick (%)	2.3	1.5	1.6	0.4	0.4	1.6
	MECHANICAL						
D638	**Tensile strength** (psi)	14000	12000	11500	8800	8600	11000
D638	**Elongation** (%)	30	60	100	150	300	15-50
D790	**Flexural modulus** (Kpsi)	460	440	420	150	150	400
	THERMAL						
D2117	**Melt point** (crystalline) (F)	663	509	428	419	374	419
D696	**Coef. of thermal expansion** (1E-05 in/in/F)	4.2	4.4	4.5	5.0	5.1	5.0
D648	**Deflection temperature** (F) at 264 psi	240	190	152	150	180	140
UL94	**Flammability rating**	V-2	V-2	V-2	V-2	—	HB
	ELECTRICAL						
D150	**Dielectric constant,** 73 F at 1 KHz	4.0	3.9	3.8	4.0	3.7	4.0
D257	**Volume resistivity** (ohm-cm) at 73 F, DAM	1E+15	1E+16	1E+15	1E+12	1E+13	—

volatile emission. Extended exposure to temperatures above 250°F will reduce moisture content to about 0.1% (similar to dry-as-molded content).

Nylons are sensitive to ultraviolet (UV) radiation. Weatherability will be reduced unless UV stabilizers are incorporated into the formulation. Carbon black is the most commonly used UV stabilizer. Carbon black lowers the ductility and toughness as a trade-off for UV stability.

Polyamides have good resistance to creep and cold flow compared to many less rigid thermoplastics. Creep resistance is better at higher levels of crystallinity as demonstrated in nylon 4/6. Creep can be calculated from long-term apparent modulus under load data.

Applications: Bearings and wear surfaces are a major use of molded, extruded, and cast nylon parts. Low friction, good wear and abrasion resistance, and the ability to operate without lubrication qualify nylons for such applications. Formulations are available which include internally dispersed solid lubricants providing even better bearing characteristics. Nylon 4/6 has the best wear resistance within the polyamide family and appears to be the best among all engineering thermoplastics.

The automotive industry is one of the largest users of nylon. Good mechanical properties and resistance to heat and fuels make these materials suitable for mechanical and electrical hardware and underhood components. Examples are timing-chain tensioners, instrument gears, cooling fans, wire connectors, thrust washers, radiators and tanks, cannisters, electrical motor components, and laminates and bobbins. Extruded nylon tubing and hose are used in hydraulic and air-conditioning systems because they are little affected by hydrocarbons and refrigerants. Braid-reinforced nylon hose is lighter than rubber hose having equivalent pressure ratings. Applications for cast nylon include many industrial equipment components. These include large journal bearings, cams, sheaves, and wear plates.

Nylon powder, applied electrostatically or by fluid bed, provides tough, wear-resistant coatings. Most coating materials are formulations of nylon 11 because of its excellent melt-flow characteristics.

Phenolic

Phenolic molding materials — sometimes called the workhorse of the thermosets — are high-performance engineering plastics. They are used principally in compounds containing either organic or inorganic reinforcing fibers and fillers. Color of phenolic compounds is limited to black or brown.

Phenolics are molded by compression, transfer, and injection methods, and by extrusion. Injection molding usually provides the fastest cycle times, but it may not be the most economical method for all parts. In long-fiber-filled compounds, for example, maximum tensile and flexural strengths are obtained by compression molding.

The phenolic resins are also used as bonding and impregnating materials. Bonding resins are available as pure phenolic compounds and, more often, formulated with other materials to provide special properties. The other materials are not necessarily limited to those normally considered fillers: for example, they may be chemicals or elastomers.

Properties: Phenolic molding compounds are characterized by low cost, superior heat resistance, high heat-deflection temperature, good electrical properties and flame resistance, excellent moldability and dimensional stability, and good water and chemical resistance. A number of compounds provide maximum performance in specific property areas. Examples are nonbleeding, heat resistant, impact, and electrical.

Applications: General-purpose molding compounds — the lowest priced phenolics — are usually wood-flour filled. Most are two-stage types used for such products as electrical wall plates, industrial switchgear, circuit breakers, and handles and knobs for small appliances. Some general-purpose compounds contain a mineral filler which improves dimensional stability. Applications include components for automotive power-brake systems and industrial terminal strips.

Special-purpose molding compounds are formulated to meet requirements such as maximum dimensional stability at high temperature (valve components in automotive transmissions), high resistance to cracking (pump housings, agricultural spray equipment), or stability in steam environments (vaporizers, steam irons, coffeemakers). Nonbleeding compounds are one-stage odor-free materials used for closures for cosmetic and drug containers.

Heat-resistant compounds are formulated from two-stage resins containing mineral fibers. Applications include motor housings for vacuum cleaners, handles for pots and pans, automatic-transmission rings, and electrical components for service in high-temperature environments. In general, these materials can withstand short-term exposure to 400°F; some grades can be subjected to 500°F. Long-term exposure ratings range from 150 to 170°C.

Impact grades of molding materials contain glass or other fibrous reinforcements. Typical applications are welding-rod holders, thermostat housings, commutators and housings for small motors, and heavy-duty electrical components.

Electrical-grade phenolic com-

Phenolics

		TYPE OF COMPOUND						
ASTM or UL test	Property	General purpose	Impact	Non-bleeding	Electrical	Heat resistant	Glass reinforced	Special purpose*
	PHYSICAL							
D792	**Specific gravity**	1.35-1.46	1.36-1.41	1.37-1.38	1.36-1.75	1.41-1.84	1.7-2.0	1.37-1.75
D570	**Water absorption**, 24 h $\frac{1}{8}$-in. thk (%)	0.6-0.7	0.6-0.9	0.8-0.9	0.05-0.20	0.30-0.35	0.05-0.2	0.20-0.40
	MECHANICAL							
D651	**Tensile strength** (psi)	6,500-7,000	6,000-7,000	6,000-7,000	5,000-7,000	5,000-6,000	6,000-12,000	7,000-9,000
D790	**Flexural modulus** (10^5 psi)	11-13	12	10	17-25	14	20-30	10
D790	**Flexural strength** (psi)	9,000-11,000	10,000	10,000	9,000-11,000	10,000	12,000-24,000	9,500
D256	**Impact strength**, Izod (ft-lb/in. of notch)	0.30-0.35	0.6-1.05	0.28	0.28-0.45	0.26	0.4-1.5	0.50
D785	**Hardness**, Rockwell E	70-95	82	82	75-88	94	92-104	76
	THERMAL							
C177	**Thermal conductivity** 10^{-4} cal-cm/sec-cm^2-°C)	7.1	7.9	—	16.0	—	—	8.8
D696	**Coef of thermal expansion** (10^{-5} in./in.-°C)	3.95	3.56	4.40	2.60	2.80	1.80	3.60
D648	**Deflection temperature** (°F) At 264 psi	275-360	270-500	370	310-400	330-380	370-550	360-430
UL 94	**Flammability rating, $\frac{1}{8}$ in.**	V-1	HB	—	V-0	V-0	V-0	HB
	ELECTRICAL							
D149	**Dielectric strength** (V/mil) Short time, $\frac{1}{8}$-in. thk	350	350-400	200	400	170	400	175
D150	**Dielectric constant** At 1 kHz	5.2-5.3	5.2-5.4	—	4.9-6.5	11.7	4.4	7.8
D150	**Dissipation factor** At 1 kHz	0.04-0.05	0.04-0.06	—	0.025-0.10	0.15	0.03	0.12
D257	**Volume resistivity** (ohm-cm) At 73° F, 50% RH	10^{11}-10^{12}	10^{11}-10^{12}	10^{12}	10^{11}-10^{13}	10^{12}	10^{12}	10^{11}
D495	**Arc resistance** (s)	100	50	—	184	181	181	—

* Chemical-resistant compound

pounds are used in small-tool housings, automotive ignition components, communications instruments, and components for aircraft instruments and computers.

Other applications of phenolic resins involve bonding, impregnating, or coating formulations. Phenolic tackifiers are used in synthetic rubbers for tires, hose, and other mechanical rubber goods. Solvent cements based on phenolics are used as structural adhesives for metal-to-rubber bonds and for bonding vinyls to various substrates. Phenolic resins are also used as heat-resistant binders for asbestos and other dry ingredients for brake linings, clutch facings, and other friction products.

Mineral-wood and glass-fiber insulation are other products that use phenolic binder resins. Phenolics are particularly suited for products that require resistance to humidity, such as refrigeration equipment.

Phenolic-resin compounds are also used as dip coatings for condensers and other electrical parts to provide moisture resistance and electrical insulation. Similar compounds are used to impregnate paper, which is used for separators in automotive batteries. Oil, air, and fuel filters are also made from phenolic-impregnated paper because of its strength, dimensional stability, and resistance to water, solvents, and oil.

Polyamide-imide

Polyamide-imides are engineering thermoplastics characterized by excellent dimensional stability, high strength at high temperature, and good impact resistance. Molded parts can maintain structural integrity in continuous use at temperatures to 500°F.

Polyamide-imide, produced by Amoco Performance Products Inc. and sold under the Torlon tradename, is available in several grades including: a general-purpose, injection-molding grade; three PTFE/graphite wear-resistant compounds; a 30% graphite-fiber-reinforced grade; and a 30% glass-fiber-reinforced grade. Additional grades are developed to meet special requirements.

Torlon resins are moldable on screw-injection-molding machines. Molds must be heated to 425°F, and the barrel and nozzle should be capable of being heated to about 700°F. High injection speed and pressure (20,000 psi or greater) are desirable. Developing optimum physical properties in injection-molded or extruded parts requires postcuring through an extended, closely controlled temperature program gradually reaching 500°F. The specific time/temperature program depends on part configuration and thickness.

Properties: Room-temperature tensile strength of unfilled polyamide-imide is about 28,000 psi and compressive strength is 32,000 psi. At 450°F, tensile strength is about 9,500 psi — as strong as many engineering plastics at room temperature — and continued exposure at 500°F for up to 8,000 h produces no significant decline in tensile properties.

Flexural modulus of 730,000 psi of the unfilled grade is increased, with graphite-fiber reinforcement, to 2.9 million psi. Retention of modulus at temperatures to 500°F is on the order of 80% for the reinforced grade. Creep resistance, even at high temperature and under load, is among the best of the thermoplastics; dimensional stability is extremely good.

Polyamide-imide is extremely resistant to flame and has very low smoke generation. The unfilled grade is rated 94V-0 at thicknesses as low as 0.008 in. and has an oxygen index of 45%. Reinforced grades have surpassed FAA requirements for flammability, smoke density, and toxic gas emission.

**ew gear material offers
utstanding performance in
oise and other problem
pplications**

**ee
urability
alculation
ssistance
X (201) 767-7797**

w Intech Power-Core™
mposite gears out-perform
er available gears where
se, wear, chemicals, vibra-
n, moisture and alignment
blems exist.
A unique combination of
uramid securely cast
und a metal hub opens
w alternatives for problem
utions and high torque
plications (e.g. worm gears,
ral bevel gears, etc.).

Satisfied customers who have replaced their steel gears report up to 12x longer gear life, often without lubrication!

Find out how Power-Core gears can help you. Call or write today for a test sample for your gear application.

INTECH Power-Core™
250 Herbert Ave., Closter, NJ 07624 TEL (201) 767-8066

Circle 587

Everything you need to know for a competitive edge in machine tool manufacturing and rebuilding ...

Super Alloy™
CASTABLE POLYMERS
simplify fabrication and assembly of machine tools

Call/write for:
- ☐ *New* 12p full-color brochure
- ☐ *New* detailed application booklet
- ☐ *Reprint* from Machine Design

ITW Philadelphia Resins
P.O. Box 309 • Montgomeryville, PA 18936
Phone: 215/855-8450 • Fax: 215/855-4688

Circle 588

Machine Design
reprints mean business.

Let us put them to work for you.

Reprints of your advertisements and "Machine Design" articles can be used as:

- ☞ *Direct mail to customers and prospects.*
- ☞ *Sales aids for your people in the field.*
- ☞ *Tools to inform stockholders and employees.*
- ☞ *Training aids for new employees.*
- ☞ *Handouts at trade shows and company meetings.*
- ☞ *New product announcements.*
- ☞ *Follow-ups to ad inquiries.*

For more information about this cost-effective way to get your message out to your customers and staff or to place an order, call Linda L. Fouts, reprints manager, at (216) 696-7000.

MACHINE DESIGN is a publication of:
Penton Publishing
1100 Superior Avenue, Cleveland, Ohio 44114

ULTRAMID®
**nylon 6, 6.6, 6.10,
copolymers and 6/6T (PA)**

FOR MORE INFORMATION, CALL:
1-800-BC-RESIN

Other BASF Plastic Materials:
- Ultraform® acetal copolymer (POM)
- Ultradur® thermoplastic polyester (PBT)
- Luran® styrene acrylonitrile (SAN)
- Luran® S acrylonitrile/styrene/acrylate (ASA)
- Terlux™ clear (ABS)
- Ultrason™ E polyethersulfone (PES)
- Ultrason™ S polysulfone (PSU)
- Ultrapek™ polyaryletherketone (PAEK)
- Elastocell® suspension components

BASF Corporation
Plastic Materials
100 Cherry Hill Road
Parsippany, NJ 07054

BASF

Circle 589

Radiation resistance of polyamide-imide is good; tensile strength drops only about 5% after exposure to 10^9 rads of gamma radiation. Chemical resistance is good, the resin being virtually unaffected by aliphatic and aromatic hydrocarbons, halogenated solvents, and most acid and base solutions. It is attacked, however, by some acids at high temperature, steam at high pressure and high temperature, and strong bases.

Torlon moldings absorb moisture in humid environments or when immersed in water, but the rate is low, and the process is reversible. For example, at 50% RH and 70°F, they absorb about 1% moisture (by weight) in 1,000 h. Parts can be restored to original dimensions by drying.

Applications: Polyamide-imide is used in structural applications requiring strength at high temperatures. Electrical/electronic uses include connectors, burn-in sockets, switches, and relays. Business-equipment components in high-heat and high-wear areas such as picker fingers and gears can be made from the material. Aerospace applications include housings, brackets, vanes, bushings, cargo rollers, standoffs, and fasteners. Compressor plates are one of many uses in the process industry; thrust washers molded from the material are used in off-road, heavy-duty vehicles. Polyamide-imide ball bearings serve in marine fittings.

Automotive uses in power-train and valve-train components include piston skirts, tappets, piston rings, valve stems, valve-spring retainers, and timing gears.

Polyamide-imide

ASTM or UL Test	General Property	Bearing purpose	Graphite-fiber grade	reinforced	Glass-fiber reinforced 30%	40%
	PHYSICAL					
D792	**Specific gravity**	1.42	1.46	1.48	1.61	1.68
D570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.33	0.28	0.21	0.24	0.21
	MECHANICAL					
D1708	**Tensile strength** (psi)					
	At 73°F	27,800	23,700	29,400	29,700	31,800
	At 275°F	16,900	16,300	22,800	23,100	25,000
	At 450°F	9,500	10,600	15,700	16,300	19,900
D1708	**Elongation** (%)					
	At 73°F	15	7	6	7	7
	At 275°F	21	20	14	15	6
	At450°F	22	17	11	12	8
D790	**Flexural modulus** (10^5 psi)					
	At 73°F	7.3	10.0	28.8	17.0	21.0
	At 275°F	5.6	7.9	27.2	15.5	20.0
	At 450°F	5.2	7.2	22.8	14.3	20.00
D790	**Flexural strength** (psi)					
	At 73°F	34,900	31,200	50,700	48,300	52,000
	At 275°F	24,800	23,500	37,600	35,900	43,600
	At 450°F	17,100	16,200	25,200	26,200	38,900
D256	**Impact strength, Izod** (ft-lb/in. of notch)	2.7	1.2	1.0	1.5	1.5
D722	**Shear strength,** (psi)					
	At 73°F	18,500	16,100	17,300	20,100	22,700
D695	**Compr strength,** (psi)					
	At 73°F	32,100	24,100	36,900	38,300	46,700
	THERMAL					
D696	**Coef of thermal exp** (10^{-5} in./in.-°F)	1.7	1.4	0.5	0.9	0.7
D648	**Deflection temp** (°F)					
	At 264 psi	532	534	540	539	536
UL 94	**Flammability rating**	V-0	V-0	V-0	V-0	V-0
D2863	**Oxygen Index** (%)	45	44	52	51	47
	ELECTRICAL					
D149	**Dielectric strength** (V/mil)	580	—	—	840	490
D150	**Dielectric constant,**					
	At 1 kHz to 1 MHz	4.2-3.9	6.0-5.4	—	4.4-6.5	4.3-4.6
D150	**Dissipation factor,**					
	At 1 kHz to 1MHz	0.026-0.031	0.037-0.042	—	0.022-0.023	0.028-0.040
D257	**Volume resistivity** (ohm-in.)	8 × 10^{16}	3 × 10^{15}	—	6 × 10^{16}	2 × 10^{16}
D257	**Surface resistivity** (ohms)	5 × 10^{18}	8 × 10^{17}	—	1 × 10^{18}	9 × 10^{17}

Polybenzimidazole

Polybenzimidazole (PBI) was first polymerized by scientists in the 1950s. In 1961, aromatic PBIs with exceptional thermal and oxidative stability were synthesized by H. Vogel and C. S. Marvel. Subsequently, Hoechst Celanese Corp. (then Celanese Corp.) became involved in PBI research through contracts with NASA and the Air Force Materials Laboratory. The company developed polymerization and fiber-spinning technology for a high-temperature resistant PBI fiber in 1963. In 1967, after a fire aboard the Apollo spacecraft, NASA initiated programs with Hoechst Celanese to develop protective clothing made from PBI fiber. PBI was used in a variety of applications for the U.S. space program, including flight suits and other protective clothing, webbings, straps,

PBI properties

ASTM test	Property	Celazole U-60, unfilled
	MECHANICAL	
D638	**Tensile strength**	23,000 psi
D638	**Elongation**	3%
D638	**Tensile modulus**	850 kpsi
D790	**Flexural strength**	32,000 psi
D790	**Flexural modulus**	950 kpsi
D695	**Compressive strength**	58,000 psi
D695	**Compressive modulus**	900 kpsi
D256	**Izod impact strength**	
	Notched	0.5 ft-lb/in.
	Unnotched	11 ft-lb/in.
	Poisson's ratio	0.34
	ELECTRICAL	
D149	**Dielectric strength**	550 V/mil
D257	**Volume resistivity**	8 × 10^{14}
D150	**Dissipation factor** (10 kHz)	0.003
D495	**Arc resistance**	186 s
	THERMAL	
D648	**Heat deflection temperature**	815°F
DMA	**Glass transition temperature**	800°F
	Thermal conductivity (77°F)	2.8 BTU-in.hr-ft^2°F
TMA	**Coef of linear thermal expansion** (75-300°F) 13 × 10 -6 in./in.°F	
	PHYSICAL	
	Specific gravity	1.3
D785	**Hardness**	115 Rockwell K
D570	**Water absorption**	0.4%

and tethers. Research in raw materials and process development continued, along with applications development, during the 1960s and 70s.

In 1983, Hoechst Celanese began commercial production of PBI fiber. Today, PBI fiber has been used successfully in firefighters' gear, industrial protective clothing, fire-blocking layers for aircraft seats, braided pump packings, and other high-performance products. Research has continued to develop other forms of PBI. In addition to Celazole molded parts, these forms include polymer additives, films, fibrids, papers, microporous resin, sizing, and coatings.

Hoechst Celanese scientists say the material has no known melting point and can withstand pressures of up to 58,000 psi. It also has demonstrated resistance to steam at 650°F. Hoechst AG is the only producer of tetraaminobiphenyl, the essential raw material used in making PBI resin.

Polycarbonate

Polycarbonates are amorphous engineering thermoplastics that offer exceptional toughness over a wide temperature range. The resins are produced in the U.S. by Dow Chemical Co. (Calibre), General Electric Co. (Lexan), and Mobay Chemical Corp. (Makrolon). The natural resins are water-clear and transparent.

Polycarbonate resins are available in general-purpose molding and extrusion grades and in special grades that provide specific properties or processing characteristics. These include flame-retardant formulations as well as grades that meet Food and Drug Administration regulations for parts used in food-contact and medical applications. Other special grades are used for blow-molding, weather and UV-resistance, glass-reinforcement, EMI, RFI, ESD-shielding, and structural-foam applications. Polycarbonate is also available in extruded sheet and film.

Polycarbonates

ASTM or UL test	Property	General purpose	High flex modulus	20% glass reinforced
	PHYSICAL			
D792	**Specific gravity**	1.2	1.25	1.35
D792	**Specific volume** (in.^{3}/lb)	23	22.2	20.5
D570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.15	0.12	0.16
	MECHANICAL			
D638	**Tensile strength** (psi)	9,000-10,500	8,000-9,600	16,000
D638	**Elongation** (%)	110-125	10-20	4-6
D638	**Tensile modulus** (10^5 psi)	3.4	4.5	8.6
D790	**Flexural strength** (psi)	11,000-15,000	15,000	19,000
D790	**Flexural modulus** (10^5) psi)	3.0-3.4	5.0	8.0
D256	**Impact strength,** Izod (ft-lb/in. of notch)	12-16	2	2
D671	**Fatigue endurance limit,** 10^7 cycles (psi)	1,000	2,000	5,000
D785	**Hardness,** Rockwell M	62-70	85	91
	THERMAL			
C177	**Thermal conductivity** (Btu-in./hr-ft^2-°F)	1.35	1.41	1.47
D696	**Coef of thermal expansion** (10^{-5} in./in.-°C)	6.6-7.0	3.2	2.7
D648	**Deflection temperature** (°F)			
	At 264 psi	260-270	288	295
	At 66 psi	280	295	300
UL 94	**Flammability rating**	HB, V-0	V-2, V-0	V-2, V-0
	ELECTRICAL			
D149	**Dielectric strength** (V/mil) Short time, ⅛-in. thk	380-400	450	490
D150	**Dielectric constant** At 1 kHz	3.02	—	—
D150	**Dissipation factor** At t 1 kHz	0.0021	—	—
D257	**Volume resistivity** (ohm-cm) At 73°F, 50% RH	$>10^{16}$	$>10^{16}$	$>10^{16}$
D495	**Arc resistance** (s)	10-120	5-120	5-120
	OPTICAL			
D542	**Refractive index**	1.586	—	—
D1003	**Transmittance** (%)	85-89	—	—
	FRICTIONAL			
—	**Coefficient of friction**			
	Self	0.52	—	—
	Against steel	0.39	—	—

*A + 1MHz

Properties: Polycarbonates are characterized by a combination of toughness, transparency, heat and flame resistance, and dimensional stability. In unnotched Izod impact tests and falling-dart tests, the unreinforced material resists breakage at very low temperatures (−65°F) and in thick sections. In a ⅛-in. section with a standard 10-mil notch radius, notched Izod impact strength is 12 to 16 ft-lb/in. of notch. This value drops to 2 to 3 ft-lb/in. of notch in sections over 0.160 in. Grades are available, however, that do not have this transition behavior and maintain high impact strength to ½ in. thick. A properly designed polycarbonate part, even in a thick section, has more impact resistance at −65°F than most plastics have at room temperature.

Humidity changes have little effect on dimensions or properties of molded parts. Even boiling water exposure does not change dimensions more than 0.001 in./in. after parts are returned to room temperature. Creep resistance is excellent throughout a broad temperature range and is improved by a factor of two to three in glass-reinforced compounds.

The insulating and other electrical characteristics of polycarbonate are excellent and almost unchanged by temperature and humidity conditions. One exception is arc resistance, which is lower than that of many other plastics.

Polycarbonates are generally unaffected by greases, oils, and acids. Nevertheless, compatibility with specific substances in a service environment should be checked with the resin supplier. Water at room temperature has no effect, but continuous exposure in hot (65°C) water causes gradual embrittlement. The resins are soluble in chlorinated hydrocarbons and are attacked by most aromatic solvents, esters, and ketones, which cause crazing and cracking in stressed parts. Grades with improved chemical resistance are available, and special coating systems can be applied to provide additional chemical protection.

Applications: Injection-molded polycarbonate components in the electrical/electronics area include connectors, switches, face plates, terminal blocks, meter covers, business-machine housings, and computer-disk packs and storage modules. Typical appliance uses are power-tool housings, vacuum-cleaner impellers and housings, grilles for fans and air conditioners, and housings, bowls and cutting wheels for food processors. Other applications include automotive instrument panels, indoor and outdoor lighting diffusers, exit signs, safety helmets, microwave ware, food-service ware, safety and prescription eyewear, kidney dialysers, blood oxygenators, solar-cell covers, boat-hatch covers, and door and window hardware. Premium-quality resins are used for compact audio discs.

Blow-molded polycarbonate products include returnable water and milk bottles, baby bottles, lighting globes, automotive spoilers, and drawer fronts for office furniture. Foam-molded polycarbonate parts include housings for computer terminals and copying machines, bus seats, roofs for recreational vehicles, and pallets and material-handling containers.

Profile-extruded products include patio-door thresholds, shelf rails, highway-delineator guideposts, automotive bright trim, and fluorescent-lighting luminaries.

A large volume use of polycarbonate is in clear extruded sheet, either in monolithic or laminated form, for safety and vandal-resistant windows in schools, self-service gas stations, banks, public buildings, trains and armored cars. Twin-wall extruded sheet is used in solar collectors and greenhouse glazing. Sheet is also thermoformed to produce skylights, outdoor signs, interior aircraft parts, safety face shields, and recreational-vehicle windshields.

Polycarbonate resins are used extensively in alloys and blends. Mobay, for example, produces compounded resins of polycarbonate with ABS, PET, and polyurethane elastomer.

Thermoplastic polyesters

ASTM or UL test	Property	Unreinforced resin	20 to 30% glass reinforced
	PHYSICAL		
D792	**Specific gravity**	1.31-1.43	1.49-1.56
D792	**Specific volume** (in.^{3}/lb)	21.1-19.4	17.1-16.4
D570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.08-0.09	0.07
	MECHANICAL		
D638	**Tensile strength** (psi)	8,000	16,500-23,000
D638	**Elongation** (%)	5-300	1-3
D638	**Tensile modulus** (10^5 psi)	2.8	12-17
D790	**Flexural strength** (psi)	12,000-14,000	24,000-33,000
D790	**Flexural modulus** (10^5 psi)	2.8-4.0	11-14
D256	**Impact strength,** Izod (ft-lb/in. of notch)	0.5	1.0-2.6
D671	**Fatigue endurance limit,** 10^7 cycles (psi)	2,850-3,500	4,000-5,000
D785	**Hardness,** Rockwell M	65-80	90-100
	THERMAL		
C177	**Thermal conductivity** (Btu-in./hr-ft^2-°F)	1.1-1.7	1.3-9.0
D696	**Coef of thermal expansion** (10^{-5} in./in.-°F)	4.3-8.9	1.3-5.4
D648	**Deflection temperature** (°F)		
	At 264 psi	122-150	395-435
	At 66 psi	302-354	435-475
UL 94	**Flammability rating**	HB to V-0	HB to V-0 and 5 V
	ELECTRICAL		
D149	**Dielectric strength** (V/mil)		
	Short time, ⅛ in. thk	420-450	480-560
D150	**Dielectric constant**		
	At 1 kHz	3.2-3.4	3.6-3.7
D150	**Dissipation factor**		
	At 1 kHz	0.0014-0.0006	0.002-0.003
D257	**Volume resistivity** (ohm-cm)		
	At 73°F, 50% RH	10^{15}-10^{16}	5-10 × 10^{15}
D495	**Arc resistance** (s)	110-130	80-130
	FRICTIONAL		
—	**Coefficient of friction**		
	Self	0.12-0.20	0.12-0.22
	Against steel	0.10-0.23	0.12-0.13

Polyester

Polyester resins, in thermoset, glass-fiber-reinforced formulations, have been used for a variety of industrial, marine, and consumer products for at least 40 years. These are the materials of "fiberglass" boats, fishing rods, and automobile body panels. More recently, thermoplastic grades of polyesters have become available for use in high-performance, injection-molded parts.

Thermoset polyesters: Polyester and alkyd molding compounds are usually based on unsaturated polyester resin systems. The term alkyd refers to those using lower amounts of monomer; when the monomer level is higher, the compound is called a polyester. At room temperature, the solutions — mixtures of resin and a liquid monomer (usually styrene) — are stable. Any of a variety of peroxide catalysts can initiate crosslinking (curing) at room temperature or at higher temperatures.

Unlike most other plastics that are based principally on a single ingredient, polyester formulations usually contain substantial amounts of several materials. Special advantages and limitations apply to each type of polyester compound, and to the various processing methods.

Fabrication of parts from thermoset polyester resins — usually glass-fiber-reinforced compounds — is more varied than with any other type of plastic. Methods for producing polyester/glass-fiber (FRP) parts include hand lay-up and spray-up for small to moderate quantities of large parts; compression molding from sheet-molding compound or from glass-fiber preforms for high-volume production of moderate-sized, intricate parts; cold-press molding for smaller components; pultrusion for constant-section shapes; and resin-injection molding, also called resin-transfer molding, a low-pressure method for intermediate production quantities.

Polyesters are also available as casting resins, both in water-extended formulations for low-cost castings, and in compounds filled with ground wood or pecan-shell flour for furniture components.

Low-profile molding resins are mixtures of polyester resins, thermoplastic polymers, and glass-fiber reinforcement. These are used to mold parts with smooth surfaces that can be painted without the need for prior sanding.

Bulk-molding compounds (BMC) are mixtures of polyester resin, short-glass fibers (⅛ to ½ in. long), filler, catalyst, and other additives for specific properties. BMC is supplied in bulk form or as extruded rope for ease of handling.

Sheet-molding compounds (SMCs) consist of polyester resin, long-glass fibers (to 2 in.), a catalyst, and other additives. They are supplied in rolls, sandwiched between polyethylene carrier films. Uniformity of SMC materials is closely controlled, making these materials especially suited for automated production.

Structural SMCs contain up to 65% glass in continuous, as well as random, fiber orientation. This compares with 20 to 35% glass, in random orientation only, of conventional SMC. For more details, see the chapter on thermoset composites.

Polyester resins are also available for use as coatings for curing by ultraviolet radiation. These 100%-solids materials cure in a matter of seconds and give off no solvents. Although some styrene may be lost upon exposure to UV radiation, the amount is small.

Glass-fiber-reinforced polyester (FRP) parts

Process and reinforcement	Glass fiber (% by wt)	Specific gravity	Density (lb/in.^{3})	Tensile strength (10^3 psi)	Flexural strength (10^3 psi)	Flexural modulus (10^5 psi)
Contact molding						
Lay-up, mat	30-45	1.4-1.6	0.050-0.058	9-18	16-28	8
Lay-up, woven roving	30-65	1.5-1.7	0.054-0.061	30-55	30-65	10-11
Spray-up	30-50	1.4-1.6	0.050-0.058	9-18	16-28	7.5
Compression molding						
Preform, mat	25-50	1.5-1.7	0.054-0.061	25-30	10-40	13-18
Bulk molding compound	15-35	1.8-2.1	0.065-0.075	4-10	10-20	14-20
Sheet molding compound	15-30	1.7-2.1	0.061-0.075	8-20	18-30	14-20
Cold press molding						
Preform, mat	20-30	1.5-1.7	0.054-0.061	12-20	22-37	13-19

Properties: Properties of thermoset polyesters are so dependent on type, compounding, and processing method that a complete listing covering all combinations would be almost impossible. However, typical strength ranges obtainable in parts fabricated from various forms of polyester/glass compounds and processed by several methods are listed in the table.

Outdoor weatherability of polyester resins specifically compounded for such service is good. Thermal, electrical, and environmental properties are generally good and can be individually improved by formulation.

Applications: The three major application areas for fiberglass-reinforced polyesters are boat hulls, architectural panels, and transportation components. Other uses include swimming-pool filter bodies, athletic equipment, housings for industrial and office equipment, storage tanks, agricultural fertilizer and seed hoppers, stackable chairs and other furniture, and bathroom components such as shower stalls and modular tub-wall segments. Many automobile front-end panels are made from glass-reinforced polyester in SMC form, by compression molding.

Pultruded parts include luggage racks for buses, boom arms for aerial lift trucks, and hollow (urethane-foam filled) insulating panels for structural uses. Pultruded structural shapes — channels, beams, and solid rod — containing up to 75% glass are replacing steel members in chemical-processing equipment, where maximum corrosion resistance is essential.

Thermoplastic polyesters: Known chemically as polybutylene terephthalate (PBT) and polyethylene terephlalate (PET), the thermoplastic-polyester molding compounds are crystalline, high-molecular-weight polymers. They have an excellent balance of properties and processing characteristics and, because they crystallize rapidly and flow readily, mold cycles are short.

In addition to several unreinforced molding resins, the polyesters are available in glass-reinforced grades. Unreinforced and glass-filled grades are available with UL flammability ratings of 94 HB and 5V.

Properties: Thermoplastic polymers have excellent resistance to a broad range of chemicals at room temperature including aliphatic hydrocarbons, gasoline, carbon tetrachloride, perchloroethylene, oils, fats, alcohols, glycols, esters, ethers, and dilute acids and bases. They are attacked by strong acids and bases.

High creep resistance and low-moisture absorption give the polyesters excellent dimensional stability. Equilibrium water absorption, after prolonged immersion at 73°F, ranges from 0.25 to 0.50% and, at 150°F, is 0.52 to 0.60%. Black-pigmented grades are recommended for maximum strength retention in outdoor uses.

Toughness is another strong point of the unreinforced, high-molecular-weight thermoplastic polymers. Unnotched specimens are rated "no-break" both at room temperature and at −40°F. In falling-dart tests, the unreinforced grades withstand more than 40 ft-lb. A toughened grade of 30% glass-reinforced resin has an unnotched impact strength of 24 ft-lb/in. — about 40% greater than that of conventional 30% glass-reinforced polyesters. Although impact strength is exceptional, special care must be observed in designing parts because polyesters are notch sensitive.

Stiffness and creep resistance can be increased by the addition of high glass loadings to thermoplastic polymers. Both 45 and 55% glass-reinforced versions are available having flexural moduli of 2,000,000 and 2,600,000 psi. These materials also have higher strength properties than conventional 30% glass-reinforced polyesters.

Warpage, which is caused by anisotropic shrinkage, has long been a problem with glass-reinforced thermoplastic polyester. Several options are available, however, to reduce warpage. For applications requiring maximum toughness, an amorphous resin, such as polycarbonate, can be blended with the polyester. Warpage is also reduced considerably with the addition of glass and mica reinforcement.

Glass-reinforced polyesters have outstanding electrical properties, which are retained after prolonged exposure to a wide range of temperature and humidity conditions. For continuous exposure, however, maximum recommended water temperature is 125°F.

Polyester film is tough, durable, and dimensionally stable. It can be metallized, embossed, slit, die cut, and laminated. It is available in crystal clear, white, opaque, or translucent forms, and its surface can be glassy smooth, matte, antistatic, adhesion promoting, or heat sealable.

Applications: Housings for products such as pumps requiring good impact strength are important uses for thermoplastic polyesters. Other applications are mechanical parts that require hard, smooth surfaces and good dimensional stability. Examples are gears, cams, rollers, and bearings. The flame-retardant grades are used in TV

Polyetherimides

ASTM or UL Test	Property	Unmodified resin	Glass-reinforced 10%	Glass-reinforced 30%
	PHYSICAL			
D792	**Specific gravity**	1.27	1.34	1.51
D570	**Water absorption**			
	At 24 h, 73°F	0.25	0.21	0.16
	At equilibrium, 73°F	1.25	1.20	0.90
—	**Mold shrinkage** (in./in.)	0.007	0.005-0.006	0.002-0.004
	MECHANICAL			
D638	**Tensile strength** (psi)	15,200	16,600	24,500
D638	**Elongation, ultimate** (%)	60	6	3
D638	**Tensile modulus** (10^5 psi)	4.3	6.5	13.0
D790	**Flexural strength** (psi)	22,000	28,000	33,000
D790	**Flexural modulus** (10^5 psi)	4.8	6.5	13.0
D256	**Impact strength,** Izod (ft-lb/in. of notch)	1.0	1.1	2.0
D785	**Hardness,** Rockwell M	109	114	114
	THERMAL			
C177	**Thermal conductivity** (Btu-in./hr-ft^2-°F)	0.85	1.22	1.56
D696	**Coef of thermal expansion** (10^{-5} in./in.-°F)	3.1	1.8	1.1
D248	**Deflection temperature** (°F)			
	At 264 psi	392	405	410
	At 66 psi	410	410	414
UL 94	**Flammability rating**	V-0 (0.016 in.)	V-0 (0.016 in.)	V-0 (0.010 in.)
D2863	**Oxygen index,** 0.060 in.	47	47	50
	ELECTRICAL			
D149	**Dielectric strength** (V/mil)			
	1/16 in.	830	—	770
D150	**Dielectric constant**			
	At 1 kHz, 50% RH	3.15	3.5	3.7
D150	**Dissipation factor**			
	At 1 kHz, 50% RH	0.0013	0.0014	0.0015
	At 2450 MHz, 50% RH	0.0025	0.0046	0.0053
D257	**Volume resistivity** (ohm-cm)	6.7×10^{17}	1.0×10^{17}	3.0×10^{16}
D495	**Arc resistance** (s)	128	85	85

and other electrical and electronic components. Parts such as connectors molded from flame-retardant PET resins can be vapor-phase and wave soldered.

Reinforced compounds are used in automotive distributor caps and for painted exterior body components. Other uses include high-density electronic connectors, terminal blocks, coil forms, and integrated-circuit carriers, and other electromechanical parts, replacing thermoset materials. The high-stiffness resins, including the foam injection-molding grades, are suited for structural applications, especially in the automotive area. The low-warp resins are primarily targeted for exterior body parts and electrical components.

Blow-molded PET bottles are used for nearly all of the 2-liter carbonated container (nonreturnable) market. The material is also for packaging food, cosmetics, and household chemicals.

Applications for the more than 150 grades of PET film products include liquid-crystal displays, metallized photocopier belts, motor and wire insulation, holographic reproduction, and magnetic tape and disks.

Polyetherimide

Polyetherimide (PEI) is an amorphous engineering thermoplastic characterized by high heat resistance, high strength and modulus, excellent electrical properties that remain stable over a wide range of temperatures and frequencies, and excellent processibility. Unmodified PEI resin is transparent and has inherent flame resistance and low-smoke evolution. The resin is produced by the General Electric Co. under the Ultem trademark.

Polyetherimide resin is available in an unreinforced grade for general-purpose injection molding, blow molding, foam molding, and extrusion, in four glass-fiber-reinforced grades (10, 20, 30, and 40% glass), in bearing grades, and in several high-temperature grades. The unreinforced grade is available as a transparent resin and in standard and custom colors. Also available is an impact-modified Ultem sheet.

The resin can be processed on conventional thermoplastic molding equipment. Melt temperatures of 660 to 800°F are typical for injection-molding applications. Mold temperatures of 150 to 350°F are required.

Polyetherimide is extruded to produce profiles, coated wire, sheet, and film. Film thicknesses as low as 0.25 mil are obtained by solvent-casting techniques. Molded and extruded parts can be machined using either conventional or laser techniques and can be bonded together or to dissimilar materials using ultrasonic, adhesive, or solvent methods.

Properties: The UL continuous-use listing of PEI is 338°F; glass-transition temperature is 419°F, and heat-deflection temperature is 392°F at 264 psi, contributing to its high strength and modulus retention for service under load at elevated temperatures. Unmodified polyetherimide is listed by UL as 94V-0 at 0.016 in. and 94-5V at 0.075 in. without the use of additives. Limiting oxygen index is 47%, one of the highest among the engineering thermoplastics. Smoke evolution, as measured in the NBS chamber test (ASTM E662), is low.

Dielectric constant of PEI remains virtually unchanged between frequencies of 60 and 10^9 Hz and temperatures of 73 to 180°F. Good insulative capabilities are demonstrated by the high volume resistivity of 6.7×10^{17} ohm-cm and dielectric strength ranging from 830 V/mil at 1/16 in. in air to greater than 6,500 V/mil for submil firm thicknesses. Arc resistance exceeds 120 s, meeting one of the UL electrical requirements for sole support of live parts.

A key feature of polyetherimide is maintenance of properties at elevated temperatures. For example, at 356°F, tensile strength and flexural modulus are 6,000 and 300,000 psi. Moduli and strengths of the glass-reinforced grades are still higher. For example, flexural modulus is 1,300,000 psi with 30% glass reinforcement, and more than 80% of this is retained at 356°F.

Polyetherimide has good creep resistance as indicated by its apparent modulus of 350,000 psi after 1,000 h at 180°F under an initial applied load of 5,000 psi. Gardner impact strength is in excess of 320 in.-lb at room temperature. The resin is notch sensitive, however, so sharp corners and other stress concentrations should be minimized for maximum impact resistance. Tensile elongation at yield of 8% provides the necessary ductility for snap-fit designs.

The resin resists a broad range of chemicals under varied conditions of stress and temperatures. Compatibility has been demonstrated with aliphatic hydrocarbons and alcohols including gasoline and gasohol, mineral-salt solutions, dilute bases, and fully halogenated hydrocarbons. Resistance to mineral acids is outstanding. The polymer is attacked by partially halogenated solvents such as methylene chloride and trichloroethane and by strong bases.

Resistance to UV radiation is good; change in tensile strength after 1,000 h of xenon arc exposure is negligible. Resistance to gamma radiation is also good, strength loss is less than 6% after 500 megarads exposure to cobalt 60 at the rate of one Mrad/h.

Hydrolytic-stability tests show that more than 85% of tensile strength is retained after 10,000 h of boiling-water immersion. The material is also suitable for applications requiring short-term or repeated steam exposure.

Applications: Principal use areas for polyetherimide moldings are electrical/electronic, automotive, aerospace, medical, and specialty applications. Electrical/electronic applications include integrated-circuit chip carriers and burn-in sockets for accelerated testing at high temperatures; electrical pin connectors requiring close point-to-point tolerances and creep resistance; noncombustible plenum connectors; high-temperature bobbins, coils, and fuseblocks; wire coatings; and insulating films for flexible circuitry. Printed-wiring boards made from reinforced PEI offer excellent dimensional stability and resistance to wave and vapor-phase soldering conditions.

Polyimides

		MOLDINGS			
		Filler			
ASTM test	**Property**	**Glass fiber**[a]	**25% graphite powder**[b]	**15% graphite powder**[c]	**Laminates**[d]
	PHYSICAL				
D792	**Specific gravity**	1.9	1.45	1.51	1.95
D792	**Specific volume** (in.^{3}/lb)	14.5	19.0	18.3	14.1
D570	**Water absorption,** 24 h. 1/8-in. thk (%)	0.2	0.6	0.2	0.3
	MECHANICAL				
D638	**Tensile strength** (psi)				
	At 70° F	27,000	5,700	9,500	50,000
	At 480° F	23,000	3,600	5,500	35,000
D638	**Elongation** (%)	<1	<1	4.5	<1
D790	**Flexural strength** (psi)				
	At 70° F	50,000	12,800	16,000	70,000
	At 480° F	36,000	9,200	9,000	50,000
D790	**Flexural modulus** (10^5 psi)				
	At 70° F	32.5	9	5.5	40
	At 480° F	24.2	7.5	3.7	32
D256	**Impact strength,** Izod (ft-lb./in. of notch)	17	0.25	0.8	13
D785	**Hardness,** Rockwell M	120	110	88	—
	THERMAL				
C177	**Thermal conductivity** (Btu-in./hr-ft^2-° F)	3.48	11.3	6.0	2.2
D696	**Coef of thermal expansion** (10^{-5} in./in.-° C)	1.4	3.4	4.7	1
D648	**Deflection temperature** (°F) At 264 psi	660	550	680	660
	ELECTRICAL				
D149	**Dielectric strength** (V/mil) Short time, 1/8-in. thk	500	—	250	625
D150	**Dielectric constant,** At 1 kHz	4.70	—	13.3	4.5
D150	**Dissipation factor,** At 1 kHz	0.003	—	0.006	0.015
D257	**Volume resistivity** (ohm-cm) At 73°F, 50% RH	5×10^{15}	—	10^{14}	6×10^{14}
D495	**Arc resistance** (s)	180	—	—	180
	FRICTIONAL				
	Coefficient of friction Against steel ($PV = 10{,}000$)	—	0.24	0.24	—

[a]Rhone-Poulenc Kinel 5504 [b]Kinel 5505 [c]DuPont SP-21 (Vespel parts) [d]Rhone-Poulenc Kerimid 601

Strength Without The Weight.

Swivel chair bases molded in glass-reinforced ZYTEL® nylon are stronger, lighter, and more economical than metal bases.

IF YOU WANT TO GET TECHNICAL

For product information and a complete application profile, call our Polyfax℠ Instant-Response Polymer Information Service. You'll receive the information instantly by fax.

Call 1-800-225-5387.

At the prompt, dial 602.

DUPONT

POLYMERS

Circle 590

Aircraft applications include high-strength jet-engine components, interior seating, wall, window, and electrical and mechanical hardware components. Underhood automotive components make use of polyetherimide's broad chemical resistance and dimensional stability at elevated temperatures. Applications include engine-condition sensors, climate-control modules, and transmission components.

The low dissipation factor of polyetherimide at gigahertz frequencies permits its use in microwave applications. Other applications include heat-resistant reflectors replacing glass in medical lamps for reduced breakage and infrared light transparency surgical instrument trays, staplers, and nebulizer components requiring repeated steam, chemical, or radiation sterilization. PEI is also finding uses in high-strength, heat and corrosion-resistant fluid and air-handling components, fasteners, and glass and graphite-fiber-reinforced composites.

Polyimide

Available both as thermoplastic and thermoset resins, polyimides (PIs) are a family of some of the most heat and fire-resistant polymers known. Moldings and laminates are generally based on thermoset resins, although some are made from thermoplastic grades. Unlike most plastics, PIs are available as laminates and shapes, molded parts, and stock shapes from some materials producers. Thin-film products — enamel, adhesives, and coatings — are usually derived from thermoplastic polyimide resins.

Laminates are based on continuous reinforcements including woven glass and quartz fabrics, or fibers of graphite, boron, quartz, or organic materials. Molding compounds, on the other hand, contain discrete fibers such as chopped glass or asbestos, or particulate fillers such as graphite powders, MoS_2, or PTFE.

Polyimide films and wire enamels are generally unfilled. Coatings may be pigmented or filled with particles such as PTFE for lubricity. Most adhesives contain aluminum powder to provide a closer match to the thermal-expansion characteristics of metal substrates and to improve heat dissipation.

PI parts are fabricated by techniques that range from powder-metallurgy methods to conventional injection, transfer, and compression molding, and extrusion methods. Porous polyimide parts are also available. Generally, those compounds that are the most difficult to fabricate have the highest heat resistance.

Properties: Polyimide parts and laminates can serve continuously in air at 500°F; service temperature for intermittent exposure can range from cryogenic to as high as 900°F. Glass-fiber-reinforced versions retain over 70% of their flexural strength and modulus at 480°F. Creep is almost nonexistent, even at high temperatures, and deformation under load (4,000 psi) is less than 0.05% at room temperature for 24 h.

These materials have good wear resistance and low coefficients of friction, both of which are further improved by PTFE fillers. Self-lubricating parts containing graphite powders have flexural strengths above 10,000 psi, which is considerably higher than those of typical thermoplastic bearing compounds.

Electrical properties of PI moldings are outstanding over a wide range of temperature and humidity conditions.

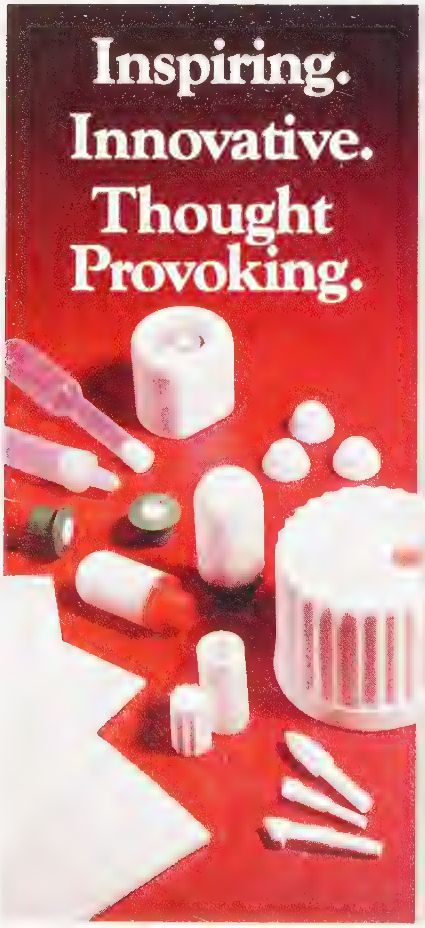
Polyimide parts are unaffected by exposure to dilute acids, aromatic and aliphatic hydrocarbons, esters, ethers, alcohols, Freons, hydraulic fluids, JP-4 fuel, and kerosene. They are attacked, however, by dilute alkalies and concentrated inorganic acids.

Polyimide adhesives maintain useful properties for over 12,000 h at 500°F, 9,000 h at 575°F, 500 h at 650°F, and 100 h at 700°F. Resistance of these adhesives to combined heat (to 575°F) and saltwater exposure is excellent.

Applications: Molded or machined polyimides are used as jet-engine vane bushings and as high-temperature electrical connectors. High-speed, high-load bearings for business machines and computer printout terminals are made from self-lubricated polyimide materials. Other applications include gear-pump gaskets, hydraulic valve seals, automotive-distributor rubbing blocks, and seal rings for air compressors and automotive transmissions.

Polyimide laminates are used in electronic, electrical, aerospace, and oil-well exploration equipment. Examples are burn-in boards for reliability testing of semiconductor devices, multilayer printed-circuit boards, vanes for sliding-vane rotary air compressors, tubes for oil-well exploration, slot wedges for large turbines, and interior aircraft panels.

Film applications include insulation for electric motors, flexible printed circuits, solar cells, heat-resistant conden-



PORex®
Porous Plastic

- For filtering, wicking, venting, supporting, diffusing, muffling, fluidizing, metering, and more.
- Opportunities in medical, industrial and consumer product applications.
- Annual quantities from 1000 parts to over 100 million.
- *Injection molded* parts produced through our APOLLO Technologies division.
- *Assembly services* offer the convenience of single-source production and assembly.

Call for *FREE samples* and discover a new approach.

1-800-241-0195

POREX
TECHNOLOGIES
500 Bohannon Road, Fairburn, GA 30213 USA
(404) 964-1421 FAX: (404) 969-0954

Circle 591

sers, insulation for aircraft and missile wire and cable, and spaghetti tubing. Polyimide film is also used in microprocessors and as the tape substrate for flight-recording devices.

Polyimide coatings are used on semiconductor devices and electrical components because of their heat resistance and low thermal expansion. Polyimide magnet-wire enamels have class C (240°C, to 20,000 h) thermal stability, and excellent radiation resistance.

Polyketones

Thermoplastic polyketones are an aromatic family of engineering resins that have excellent thermal stability and high-temperature properties. Two resins within this family, polyetheretherketone (PEEK) and polyetherketone (PEK), are currently available. PEEK, however, is considered the more commercially important of the two.

PEEK resins are marketed by ICI Advanced Materials under the Victrex tradename. PEK resins are offered by Amoco under the Kadel tradename, and by ICI, BASF, and Hoechst Celanese. In addition, Du Pont supplies a polyetherketoneketone (PEKK) resin. The following discussion focuses on PEEK.

PEEK is a high-temperature, crystalline thermoplastic resin suitable for high-performance injection moldings, wire coatings, and advanced composite structures. It offers an excellent combination of thermal and combustion characteristics, and it resists a wide range of solvents and proprietary fluids.

Properties: The wholly aromatic structure of PEEK contributes to its high-temperature performance. And its crystalline character gives it resistance to organic solvents, resistance to dynamic fatigue, and retention of ductility on short-term heat aging. Molded PEEK components absorb much less water than many other thermoplastics.

At room temperature, PEEK is tough, strong, rigid, has excellent load-bearing properties over long periods, and has outstanding resistance to abrasion. On a short-term basis, the material is suitable for service temperatures in excess of 300°C. The resin also has excellent thermal stability for continuous operation. A lifetime of 50,000 h can be expected for PEEK at 250°C. With no flame-retardant additives or

Polyetheretherketone

ASTM or UL test	Property	Unreinforced	Glass reinforced 20%	Glass reinforced 30%	30% carbon reinforced
	PHYSICAL				
D792	**Specific gravity**	1.32	1.43	1.49	1.44
D792	**Specific volume** (in.^{3}/lb)	21.0	19.3	18.6	—
D570	**Water absorption,** 24 h, 1/8-in. thk (%)	0.5	—	0.11	0.06
	MECHANICAL				
D638	**Tensile strength** (psi)	13,300	17,800	22,800	30,200
D638	**Elongation** (%)	50	2.5	2.2	1.3
D638	**Tensile modulus** (10^5 psi)				
	At 302°F	1.6	—	—	—
	At 356°F	0.58	—	—	—
D790	**Flexural strength** (psi)	24,700	27,800	33,800	46,100
D790	**Flexural modulus** (10^5 psi)	5.3	9.7	15	18.9
D256	**Impact strength, Izod** (ft-lb/in. of notch)	1.6	1.6	1.8	1.6
	THERMAL				
C177	**Thermal conductivity** (10^{-4} cal-cm/sec-cm^2-°C)	6.0	—	10.4	22.1
D696	**Coef of thermal expansion** (10^{-5} in./in.-°C)				
	<150°C	4.7	2.4	2.2	1.5
	>150°C	10.8	—	—	—
D648	**Deflection temperature** (°F)				
	At 264 psi	320	545	600	600
UL 94	**Flammability rating,** 1/8 in.	V-0	V-0	V-0	V-0
	ELECTRICAL				
D150	**Dielectric constant**				
	At 1 kHz	3.3	—	—	—
D150	**Dissipation factor**				
	At 1 kHz	0.003	—	—	—
D257	**Volume resistivity** (ohm-cm) At 73°F, 50% RH	1.4×10^5	4.9×10^{16}	—	—

Pretty. Tough.

METCO uses ZYTEL® glass-reinforced, super-tough nylon for its saws and other power tools for a high-quality surface appearance and excellent impact resistance that exceeds UL requirements in drop tests.

IF YOU WANT TO GET TECHNICAL

For product information and a complete application profile, call our Polyfax℠ Instant-Response Polymer Information Service. You'll receive the information instantly by fax.

Call 1-800-225-5387.

At the prompt, dial 502.

DU PONT

POLYMERS

Circle 592

halogens, PEEK has a limiting oxygen index of 35%, meets UL94V-0 requirements, and has extremely low smoke emission.

PEEK has good resistance to aqueous reagents, with long-term proven performance in water at 260°C. Resistance to attack is over a wide pH range, varying from 60% sulfuric acid to 40% sodium hydroxide at elevated temperatures. It is attacked, however, by some concentrated acids. No solvent attack has been observed on molded parts, although some solvents cause crazing of highly stressed PEEK-coated wire. Orientation of PEEK below its melting point overcomes this problem.

Preliminary tests suggest that radiation resistance is extremely good. Tightly coiled PEEK-coated wire samples have withstood 1,100 megarads without significant degradation. Like more polyaromatic resins, PEEK moldings are degraded by UV exposure during outdoor weathering. The effect is minimal, however, over a 12-month period for both natural and pigmented moldings. For use in extreme weather conditions, paint or other coatings are recommended for protection from UV degradation.

Applications: Typical applications of PEEK thermoplastic resin include insulation for wire and cable for demanding applications involving aircraft, military, nuclear-plant, oil-well, and underground-railway equipment. Injection-molded applications include pump impellers, electrical connectors, valve seals, and fairing members for aircraft.

Polyolefins

(Polyethylene, polypropylene, ethylene-vinyl acetate, ionomer, polybutylene, polymethylpentene, polydicyclopentadiene)

Polyolefin homopolymers are made from ethylene, propylene, butylene, and methyl pentene. Other olefin monomers such as pentene and hexene are used to make copolymers.

Because the chemical and electrical properties of all olefins are similar, they often compete for the same applications. They differ from each other primarily in their crystalline structure. However, since strength properties vary with the type and degree of crystallinity, the tensile, flexural, and impact strength of each polyolefin may be quite different. Stress-crack resistance and useful temperature range also vary with crystalline structure.

In addition to the solid polyolefin resins, these materials are also available as beads from which very low density (1.25 to 5.0 lb/ft^3) foam shapes and blocks are produced. Resilience and energy-absorption properties of these products are exceptional compared to those of conventional polystyrene foams. Polymers available as moldable beads include polyethylene, polypropylene, and a PE/polystyrene copolymer alloy.

The bead forms can be processed by the same methods used for expandable polystyrene (EPS). After the beads are expanded (20 to 40 times that of the solid resin) and conditioned, they are poured into a mold and heated, usually by direct injection of steam. This softens, expands further, and fuses the particles together, forming a uniform, void-free, closed-cell shape. After molding, the shapes are usually annealed by being stored at 120 to 160°F to stabilize shape and dimensions.

Because they contain 80 to 95% air by volume, the foamed shapes are not nearly as strong as solid moldings. They are used primarily to cushion impact, insulate thermally, and provide high stiffness-to-weight core materials in composite components. An important application for polypropylene foam is in bumper cores for automobiles. A 3 to 4-in.-thick section of foam at 2 to 4 lb/ft^3 can absorb the energy of a 5-mph impact. Package cushioning for fragile and valuable products such as electronic or audio components is another application for either PE or PP foam. The toughness of PE/PS alloy foams qualifies them for material-handling applications where repeated use is required.

The principal resins of the polyolefin family are polyethylene and polypropylene. Other polyolefin polymers and copolymers described here are ethylene-vinyl acetate, ionomer, polybutylene, and polymethyl pentene.

Polyethylene: The largest volume thermoplastic polymers used today, polyethylene is available in a variety of grades that have an equally wide range of properties. Some are flexible, others are rigid; some have low impact strength, others are nearly unbreakable; some have good clarity, others are opaque. Service temperatures can range from −40 to 200°F. In general, however, polyethylenes are characterized by toughness, excellent chemical resistance and electrical properties, low coefficient of friction, near-zero moisture absorption, and ease of processing.

Polyethylenes are classified according to density: low, medium, and high. A fourth type — ultrahigh-molecular-weight polyethylene (UHMWPE) — is in the medium-to-high density range. Properties of this high-performance plastic are entirely different from those of conventional polyethylenes. Also available is crosslinked polyethylene — a special grade, which, by chemical or irradiation treatment, becomes essentially a thermoset material with outstanding heat resistance and strength.

Low-density PE: LDPE, the first of the polyethylenes to be developed, has good toughness, flexibility, low-temperature impact resistance, clarity in film form and relatively low heat resistance. Like the higher-density grades, LDPE has good resistance to chemical attack. At room temperature, it is insoluble in most organic solvents but is attacked by strong oxidizing acids. At higher temperatures, it becomes increasingly more susceptible to attack by aromatic, chlorinated, and aliphatic hydrocarbons.

Polyethylene is susceptible to environmental and some chemical stress cracking. Wetting agents such as detergents accelerate stress cracking. Some copolymers of LDPE are available with improved stress-crack resistance.

About half of LDPE production goes into packaging applications such as industrial bags, shrink bundling, soft goods, and produce and garment bags. Other applications include blow-molded containers and toys, hot-melt adhesives, injection-molded housewares, paperboard coatings, and wire insulation. LDPE resins are rotationally molded into large agricultural tanks, chemical shipping containers, tote boxes, and battery jars.

One of the fastest-growing plastics is linear low-density polyethylene (LLDPE), used mainly in film applications but also suitable for injection, rotational, and blow molding. Properties of LLDPE are different from those of conventional LDPE and HDPE in that impact, tear, and heat-seal strengths and environmental stress-crack resistance of LLDPE are significantly higher. Major uses at present are grocery bags, industrial trash bags, liners, and heavy-duty shipping bags for such products as plastic resin pellets.

High-density PE: Rigidity and tensile strength of the HDPE resins are considerably higher than those properties in the low and medium-density materials. Impact strength is slightly lower, as is to be expected in a stiffer material, but values are high, especially at low temperatures, compared to those of many other thermoplastics.

HDPE resins are available with broad, intermediate, and narrow mo-

ASTM test	Property	Low density	Medium density	High density	Ultrahigh molecular weight
	PHYSICAL				
D792	**Specific gravity**	0.910-0.925	0.926-0.940	0.941-0.965	0.928-0.941
D792	**Specific volume** (in.^{3}/lb)	30.4-29.9	29.9-29.4	29.4-28.7	29.4
D570	**Water absorption, 24 h,** 1/8-in. thk (%)	<0.01	<0.01	<0.01	>0.01
	MECHANICAL				
D638	**Tensile strength** (psi)	600-2,300	1,200-3,500	3,100-5,500	4,000-6,000
D638	**Elongation** (%)	90-800	50-600	20-1,000	200-500
D638	**Tensile modulus** (10^5 psi)	0.14-0.38	0.25-0.55	0.6-1.8	0.20-1.10
D790	**Flexural modulus** (10^5 psi)	0.08-0.60	0.60-1.15	1.0-2.0	1.0-1.7
D256	**Impact strength,** Izod (ft-lb/in. of notch)	No break	0.5-16	0.5-20	No break
D785	**Hardness,** Rockwell R	10	15	65	67
	THERMAL				
C177	**Thermal conductivity** (10^{-4} cal-cm/sec-cm^2-°C)	8.0	8.0-10.0	11.0-12.4	11.0
D696	**Coef of thermal expansion** (10^{-5} in./in.-°F)	5.6-12.2	7.8-8.9	6.1-7.2	7.8
D648	**Deflection temperature** (°F)				
	At 264 psi	90-105	105-120	110-130	118
	At 66 psi	100-121	120-165	140-190	170
	ELECTRICAL				
D149	**Dielectric strength** (V/mil) Short time, 1/8-in. thk	460-700	460-650	450-500	900*
D150	**Dielectric constant** At 1 kHz	2.25-2.35	2.25-2.35	2.30-2.35	2.30-2.35
D150	**Dissipation factor** At 1 kHz	0.0002	0.0002	0.0003	0.0002
D257	**Volume resistivity** (ohm-cm) At 73°F, 50% RH	10^{15}	10^{15}	10^{15}	10^{18}
D495	**Arc resistance** (s)	135-160	200-235	—	—
	OPTICAL				
D542	**Refractive index**	1.51	1.52	1.54	—
D1003	**Transmittance** (%)	4-50	4-50	10-50	—

*kV/cm.

lecular-weight distribution, which provides a selection to meet specific performance requirements. As with the other polyethylene grades, very-high-molecular-weight copolymers of HDPE resins are available with improved resistance to stress cracking.

Applications of HDPE range from film products to large, blow-molded industrial containers. The largest market area is in blow-molded containers for packaging milk, fruit juices, water, detergents, and household and industrial liquid products. Other major uses include high-quality, injection-molded housewares, industrial pails, food containers, and tote boxes; extruded water and gas-distribution pipe, and wire insulation; and structural-foam housings.

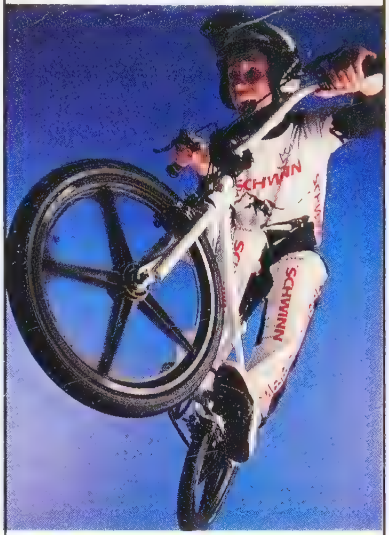
HDPE resins are also used to rotationally mold large, complex-shaped products such as fuel tanks, trash containers, dump carts, pallets, agricultural tanks, highway barriers, and water and waste tanks for recreational vehicles.

A special category of HDPE known as high-molecular-weight HDPE (HMW-HDPE) offers outstanding toughness and durability, particularly at low temperatures. These characteristics result from a unique combination of high average molecular weight (250,000 to 500,000), and a bimodal molecular-weight distribution.

In blow-molding applications, HMW-HDPE allows drum manufacturers to meet DoT and OSHA specifications. In pipe production, HMW-HDPE meets PE-3408, currently the highest strength rating for PE pipe. Extruded sheet applications include pond liners, truck-bed liners, and outdoor leisure products. The primary market, however, for HMW-HDPE is in film applications, where its toughness allows downgaging in merchandise bags and trash bags. The material is also suited for use in T-shirt-type grocery sacks requiring high handle strength.

UHMWPE: Ultrahigh-molecular-weight polyethylene was originally defined as a polyethylene whose average

Zytel.® For Lightweight Wheels That Can Take A Pounding.



Motocross (BMX) bike wheels molded with a combination of ZYTEL® super-tough nylon and glass-reinforced ZYTEL provide high impact strength and stiffness in a lightweight construction that's tougher than spoke steel or aluminum.

IF YOU WANT TO GET TECHNICAL

For product information and a complete application profile, call our Polyfax℠ Instant-Response Polymer Information Service. You'll receive the information instantly by fax.

Call 1-800-225-5387.

At the prompt, dial 702.

DU PONT

POLYMERS

Circle 593

molecular weight, as measured by the solution-viscosity method, is greater than 2,000,000. (Molecular weight of HDPE ranges from 100,000 to 500,000.) Over the years, producers and processors of UHMWPE materials have tried to reach agreement on just how high is "ultrahigh." Values proposed in the past have ranged from as low as 1,000,000 to over 3,500,000. Also in dispute was the question of the relationship between molecular weight and properties of UHMWPE in finished parts.

Several years ago, an ASTM task force agreed on the value of 3,100,000 molecular weight as the dividing line, above which the UHMW description should apply. Resin properties increase with increasing MW and start to level off at the 3,100,000 value. Also, processibility is more difficult above that dividing line, and material cost rises more rapidly. In 1981, the standard of 3,100,000 or higher for UHMWPE was approved by ASTM, and the final, full-society vote endorsed that recommendation, which is now defined in ASTM D4020.

As with most high-performance polymers, processing of UHMWPE is not easy. Because of its high melt viscosity (it does not register a melt-flow index), conventional molding and extrusion processes would break the long molecular chains that give the material its excellent properties. Methods used currently are compression molding, ram extrusion, and warm forging of extruded slugs. Developmental work is being done on injection molding of UHMWPE resins, but the process forces the polymer to behave in a manner that is not conducive to maintaining its molecular structure. Compression-molded sheets as large as 5 × 12 ft are available.

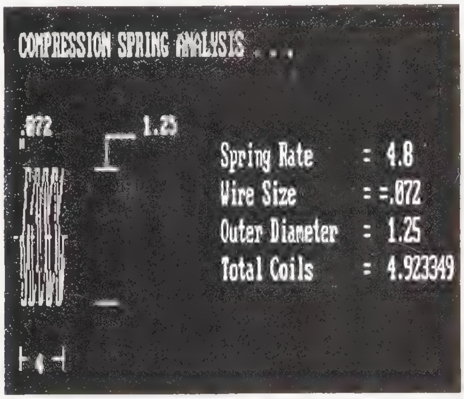
UHMW polyethylene has outstanding abrasion resistance and a low coefficient of friction. Impact strength is high, and chemical resistance is excellent. The material does not break in impact strength tests using standard notched specimens; double-notched specimens break at 20 ft-lb/in. Crystalline melting point of the material is 267°F. Recommended maximum service temperature is about 200°F, however, because of a high coefficient of thermal expansion.

Applications of UHMWPE include conveyor wear strips and guide rails, paper-machine suction-box covers, chute linings, snowmobile-track sprockets, bearings, parts for textile looms, pipe for distribution of slurry materials, and other components requiring abrasion resistance, impact

Design Springs In Seconds On Your PC With SPRINGPac

This microcomputer program can be used for the design, testing and validation of **Extension, Compression, Torsion, Flat, Motor, and Belleville** springs. —

- *Spread-sheet format for easy data entry . . .*
- *14 ASTM material specs, or define your own .*
- *Accepts rectangular wire for compression springs . . .*
- *Calculates stress in hooks of extension springs .*
- *Accepts springs with two loads . . .*
- *Design with English or Metric units . . .*
- *Saves designs for later retrieval . . .*
- *Technical support with telephone back-up. . .*



```
COMPRESSION SPRING ANALYSIS . . .

Spring Rate      =  4.8
Wire Size        = =.872
Outer Diameter   =  1.25
Total Coils      =  4.923349
```

Program calculations include usual spring design parameters plus:

Dimensioned graphics of spring profile,
Critical frequency,
Spring weight,
Number of cycles to failure.

SPRINGPac disks and user manual $495
(for IBM family or 100% compatibles.
Requires color or enhanced graphics card)

SATISFACTION GUARANTEED!
Use SPRINGPac on your PC. If it doesn't perform as described, just return the program within 30 days for full refund or credit

Order toll-free 800-321-7003
(in Ohio 216/69[illegible])

or send your order to:

PENTON EDUCATION DIVISION
1100 Superior Avenue
Cleveland, Ohio 44114

strength, and a low-friction coefficient. These plastics have outperformed other materials, including metals, in these applications.

Polypropylene: Produced from propylene gas, polypropylene (PP) resins are semitranslucent and milky white in color and have excellent colorability. Most PP parts are produced by injection molding, blow molding, or extrusion of either unmodified or reinforced compounds. Other applicable processes are structural-foam molding and solid-phase and hot-flow stamping of glass-reinforced sheet stock (a product of Azdel Inc., a joint venture of PPG Industries and General Electric Plastics).

Properties: Polypropylene is a low-density resin that offers a good balance of thermal, chemical, and electrical properties, along with moderate strength and moderate cost. Strength properties are increased significantly with glass-fiber reinforcement. Increased toughness is provided in special, high-molecular-weight, rubber-modified grades.

Electrical properties of PP moldings are affected to varying degrees by service temperature. Dielectric constant is essentially unchanged, but dielectric strength increases and volume resistivity decreases with increased temperature.

Polypropylene has limited heat resistance, but heat-stabilized grades are available for applications requiring prolonged use at elevated temperatures. Useful life of parts molded from such grades may be as long as five years at 250°F, ten years at 230°F, and 20 years at 210°F. Specially stabilized grades are UL-rated at 120°C (248°F) for continuous service.

PP resins are unstable in the presence of oxidative conditions and UV radiation. Although all grades are stabilized to some extent, specific stabilization systems are often used to suit a formulation for a particular environment. Polypropylenes resist chemical attack and staining and are unaffected by aqueous solutions of inorganic salts or mineral acids and bases, even at high temperatures. They are not attacked by most organic chemicals, and there is no solvent for the resin at room temperature. The resins are attacked, however, by halogens, fuming nitric acid and other active oxidizing agents, and by aromatic and chlorinated hydrocarbons at high temperatures.

Polypropylene

ASTM or UL test	Property	Unmodified resin	Glass reinforced	Impact grade
	PHYSICAL			
D792	**Specific gravity**	0.905	1.05-1.24	0.89-0.91
D792	**Specific volume** (in.^{3}/lb)	30.8-30.4	24.5	30.8-30.5
D570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.01-0.03	0.01-0.05	0.01-0.03
	MECHANICAL			
D638	**Tensile strength** (psi)	5,000	6,000-14,500	2,800-4,400
D638	**Elongation** (%)	10-20	2.0-3.6	350-500
D638	**Tensile modulus** (10^5 psi)	1.6	4.5-9.0	1.0-1.7
D790	**Flexural modulus** (10^5 psi)	1.7-2.5	3.8-8.5	1.2-1.8
D256	**Impact strength,** Izod (ft-lb/in. of notch)	0.5-2.2	1.0-5.0	1.0-15
D785	**Hardness,** Rockwell R	80-110	110	50-85
	THERMAL			
C177	**Thermal conductivity** (10^4 cal-cm/sec-cm^2-°C)	2.8	—	3.0-4.0
D696	**Coef of thermal expansion** (10^{-5} in./in.-°F)	3.2-5.7	1.6-2.9	3.3-4.7
D648	**Deflection temperature** (°F)			
	At 264 psi	125-140	230-300	120-135
	At 66 psi	200-250	310	160-210
UL94	**Flammability rating***	HB	HB	HB
	ELECTRICAL			
D149	**Dielectric strength** (V/mil) Short time, ⅛-in. thk	500-660	475	500-650
D150	**Dielectric constant** At 1 kHz	2.2-2.6	2.36	2.3
D150	**Dissipation factor** At 1 kHz	0.0005-0.0018	0.0017	0.0003
D257	**Volume resistivity** (ohm-cm) At 73° F, 50% RH	10^{17}	2×10^{16}	10^{15}
D495	**Arc resistance** (s)	160	100	—

*V-2, V-1, and V-0 grades are also available.

Applications: Unreinforced polypropylene is used for packaging applications such as blow-molded pharmaceutical, medical, cosmetic, and food containers. Structural-foam grades are used for furniture and for automotive seatbacks.

Both reinforced and unreinforced grades are used in automotive, appliance, and electrical applications. Examples are automotive battery cases, lamp housings, blower wheels, fan shrouds, fender liners, and glove boxes; appliance pumps, blower housings, fan blades, and vegetable bins; and as sole support for current-carrying electrical parts, coil bobbins, cable covers, TV yokes, fuse housings, and insulators.

Ethylene-vinyl acetate: EVA copolymers, which are derived from LDPE technology, are polyolefins that approach elastomeric materials in softness and flexibility. Yet, they can be injection, blow, compression, transfer, and rotationally molded; they are also extruded into film, sheeting, pipe, and profiles. Melt temperatures for these resins are generally 50 to 75°F lower than for polyethylenes. The resins can be pigmented to a broad range of colors, from pastels to deep hues.

EVA parts have good clarity and gloss, stress-crack resistance, barrier properties, low-temperature toughness, adhesive properties, and resistance to UV radiation. They have little or no odor, and they retain flexibility at low temperatures. Although their electrical properties are not as good as those of low-density polyethylene, EVA copolymers are competitive with rubber and vinyl products normally used for electrical applications.

The main limitation of EVA copolymers is their comparatively low resistance to heat and solvents. Chlorinated hydrocarbons, straight-chain paraffinic solvents, and benzene and its derivatives attack the resins. They are not attacked, however, by alcohols, glycols, or weak organic acids. Heat-deflection temperature at 66 psi is about 145°F.

EVA copolymers are used principally in specialty applications, competing with plasticized PVC and rubber. FDA approves the use of these resins in direct contact with foods. Tubing made from EVA resins is used in medical equipment and in beverage-vending, milk-packaging, and beer-dispensing equipment. Molded mechanical EVA parts include appliance bumpers, blow-molded bellows for air-operated toys, seals, and gaskets. The resins are also used in hot-melt adhesives.

Ionomer: Interchain ionic bonding is what distinguishes ionomers from other polymers. These ionic crosslinks occur randomly between the long-chain molecules, producing properties that are usually associated with high-molecular-weight materials. At normal thermoplastic processing temperatures, however, the ionic bonding diminishes, allowing processing in conventional extruders and injection-molding equipment.

Density of ionomers ranges from 0.94 to 0.97 gm/cm^3. They are extremely tough, having tensile impact strengths as high as 600 ft-lb/in.^{2} and tensile strength as high as 5,000 psi, with elongation in the range of 300 to 500%. In addition, ionomers have excellent abrasion resistance (NBS Index as high as 640) and optical clarity (haze as low as 40%).

A compounded ionomer product is also available that is stiffer and has better heat resistance than the standard grades, and retains its excellent impact resistance. This product, intended for semirigid parts, resists many chemicals, solvents, greases, and oils.

The clarity, strength, and good adhesion of ionomer film to metal foils are responsible for its widespread use in food packaging, often as a heat-seal layer in composite structures. High impact strength and cut resistance have led to its use as bowling-pin and golf-ball covers. Automotive uses are based on impact toughness, light weight, and paintability. Foam injection-molded parts have replaced heavier rubber and metal bumpers guards and license-plate holders.

Footwear uses include box toes, heel counters, and injection-molded athletic soles to which metal cleats can be insert molded or spin welded. Ionomer is used in ski boots and ice skates to provide lightweight durable shells. Ionomer foams are used in ski-lift pads, boat bumpers, marine navigation buoys, and wrestling mats. Foamed sheet is used for thermal insulation on pipes and in covers for hot-water storage tanks.

Polybutylene: These resins are semicrystalline thermoplastics manufactured in the U.S. by Shell Chemical Co. and sold under the trademark Duroflex. Compared to other polyolefins, they have superior resistance to creep and stress cracking. Films made from polybutylene have high tear resistance, toughness, and flexibility. Chemical and electrical properties are similar to those of polyethylene and polypropylene, but the degree of crystallinity is much lower. This results in a rubberlike plastic that has very low molded-in stress. Rotationally molded polybutylene parts are virtually stress free.

The major applications for polybutylene resins are in pipe, packaging, hot-melt adhesives, and sealants. It is used as film for industrial refuse bags that resist bursting, puncturing, and tearing. Polybutylene pipe for cold-water applications has a higher burst strength than pipe made from any other polyolefin. Large-diameter pipe is used in mining and power-generation systems to convey abrasive materials.

Polymethylpentene: Major advantages of polymethylpentene (PMP) over other polyolefins are transparency in thick sections, short-time heat resistance to 400°F, and lower specific gravity. A moderately crystalline plastic, PMP is transparent because, unlike other polyolefins, its crystalline and amorphous phases have the same index of refraction. Almost optically clear, it has a light-transmission value of 90%, just slightly less than acrylic.

Polymethylpentene retains most of its physical properties in brief exposure to 400°F, but is not stable at temperatures over 300°F without antioxidant additives. In clear form, it is not recommended for long-term exposure to UV environments.

Chemical resistance and electrical properties of PMP are similar to those of other polyolefins except that it retains these properties at higher temperatures than either polyethylene or polypropylene. In this respect, it compares favorably with PTFE up to 300°F. Parts molded from the resin are hard and shiny, yet impact strength is high at temperatures down to −20°F. Specific gravity (0.83) is the lowest of any commercial solid plastic.

A major use of polymethylpentene is in molded containers for foods that are quick-frozen, then heated later in the same container. Other commercial applications include bottle closures, hot-liquid level indicators, transparent plumbing systems, coffeemaker bowls, medical syringes, laboratory ware, and light diffusers. Electrical/electronic applications include wire coatings and components for microwave equipment.

Polydicyclopentadiene: PDCPD is a thermoset polymer formed by the metathesis polymerization of dicyclopentadiene (DCPD). DCPD components can be used in reaction injection molding, structural RIM, resin-transfer molding, casting, and other liquid-molding processes.

In these processes, low viscosity (less than 350 centipoises) A and B components are mixed at a 1:1 ratio and pumped into a closed mold at pressure less than 50 psi. The polymerization is carried out in the mold, forming a rigid, high-impact, unreinforced plastic. Fillers can be included in the components to enhance polymer rigidity or lower the coefficient of linear thermal expansion. When continuous glass mat reinforcement is preplaced in the mold before injection, as in the SRIM and RTM processes, the resulting composite formed has structural properties.

PDCPD has low density and a unique balance of rigidity and impact while being resistant to chemical and having a hydrophobic character. The creep resistance is typical of a thermoset polymer when it is utilized in a temperature range which is best characterized by the heat deflection temperature of 264 psi at 100 to 115°C, depending on formulation. PDCPD develops a thin oxidized layer when exposed to oxidizing or UV conditions, which inhibit further oxidation by acting as a barrier to oxygen. All grades are stabilized for specific environmental requirements. Parts requiring long-term outdoor exposure can be painted with the surface readily accepting most paint systems.

Unreinforced PDCPD is used for recreational vehicle housings, car and truck body parts, materials-handling components, chemical-resistant equipment, and industrial housings. Continuously reinforced polymer is being evaluated for structural automobile body panels and marine applications.

Polyphenylene ether

Alloys, or blends of PPE and polystyrene in various proportions, are marketed under the tradenames of Noryl and Prevex (General Electric). The resins are processed by conventional injection-molding, extruding, and thermoforming methods. Structural-foam parts are processed in standard foam-molding systems, using either direct induction of nitrogen gas or conventional chemical-blowing agents.

Polyphenylene ether is produced by a process based on oxidative coupling of phenolic monomers. The result, a resin that has good mechanical properties and thermal stability, is then blended with polystyrene to improve processibility. Available grades of molding resins, including glass-reinforced and platable compounds and heat-resistant grades (containing nylon), in addition to extrusion and foamable grades. All resins can be furnished in a wide range of colors.

Polyphenylene ether resins

ASTM or UL test	Property	Standard	Glass reinforced	Extrusion	Platable
	PHYSICAL				
D792	**Specific gravity**	1.06-1.10	1.21-1.36	1.06-1.10	1.05
D792	**Specific volume** (in.^{3}/lb)	25.2-26.2	20.4-22.9	25.2-26.2	—
D570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.07	0.07	0.07	0.07
	MECHANICAL				
D638	**Tensile strength** (psi)	7,000-9,600	14,500-17,800	7,800-11,000	7,000
D638	**Elongation** (%)	50-60	4.6	15-60	60
D638	**Tensile modulus** (10^5 psi)	3.55-3.80	9.25-1.2	3.55-3.80	—
D790	**Flexural strength** (psi)	8,200-15,000	18,500-20,000	12,800-16,000	9,800
D790	**Flexural modulus** (10^5 psi)	3.0-3.6	7.5-11	3.6	3.0
D256	**Impact strength,** Izod (ft-lb/in. of notch)	5.0-10.0	2.3	3.10	5.0
D671	**Fatigue endurance limit,** 2×10^6 cycles (psi)	1,850-2,500	4,000-5,000	1,850-2,500	—
D785	**Hardness,** Rockwell	R115-119	L106-108	R115-119	—
	THERMAL				
C177	**Thermal conductivity** (Btu-in./hr-ft^2-°F)	1.50	1.10	1.50	—
D696	**Coef of thermal expansion** (10^{-5} in./in.-°C)	3.3-3.8	1.4-2.0	3.3-3.8	3.5
D648	**Deflection temperature** (°F)				
	At 264 psi	190-300	270-300	185-300	235
	At 66 psi	220-315	280-317	230-315	—
UL 94	**Flammability class**	HB, V-1, V-0	HB, V-1	HB-V-1, V-0	HB
	ELECTRICAL				
D149	**Dielectric strength** (V/mil) Short time, ⅛-in. thk	400-630	420-600	400-550	—
D150	**Dielectric constant** At 1 MHz	2.64-2.68	2.85-3.11	2.64-2.68	—
D150	**Dissipation factor** At 1 MHz	0.0009-0.0024	0.0014-0.0021	0.0009-0.0047	—
D257	**Volume resistivity** (ohm-cm) At 73°F 50% RH	10^{17}	10^{17}	10^{17}	—
D495	**Arc resistance** (s)	75	70-120	75	—

Properties: Polyphenylene ether blends are characterized by outstanding dimensional stability, the lowest water absorption of the engineering thermoplastics, broad temperature ranges, excellent mechanical and thermal properties, and excellent dielectric properties over a wide range of frequencies and temperatures. Several injection-molding and extrusion grades are rated UL94V-1, or V-0, including glass-reinforced versions. Foamable grades have service-temperature ratings of up to 205°F in ½-in. sections.

Because of their excellent hydrolytic stability, both at room and elevated temperatures, PPE blend parts can be repeatedly steam-sterilized with no significant change in properties. In exposure to aqueous environments, dimensional changes are low and predictable. Resistance to acids, bases, and detergents is excellent. The material is attacked, however, by many halogenated or aromatic hydrocarbons. Prototype testing of components requiring exposure to such environments is recommended.

Applications: Automotive uses of PPE blends include plated grilles and trim, connectors, moldings, wheel covers, mirror housings, instrument panels, and rear shelves. Housings and chassis for small and major appliances and business machines are other components made from these materials because of requirements of strength, dimensional stability, and heat resistance. Similar housings and other large parts are also made from the foamable grade.

Electrical construction equipment and TV receivers also use a number of molded parts. Examples are outlet boxes, fans, TV cabinets, connectors, and tuner and deflection-yoke components requiring stiffness, dimensional stability, and good heat and flame resistance.

Pump impellers, swimming-pool pumps, and shower heads are typical applications using these resins because of their hydrolytic stability, strength, and chemical resistance.

Typical applications for extrudable resins are cable protective covers, lighting tracks, busbar sleeves, interlocking wiring covers, and scrubber-vane mist eliminators.

Polyphenylene sulfide

Polyphenylene sulfide (PPS) is a crystalline, high-performance engineering thermoplastic characterized by outstanding high-temperature stability, inherent flame resistance, and broad chemical resistance. PPS resins and compounds manufactured in the U.S. are tradenamed Ryton by their producer, Phillips Chemical Co. PPS compounds are also marketed in the U.S. by several other companies that buy the resin from foreign sources.

A wide range of injection-molding grades of PPS is available. The series having various glass-fiber levels (designated R-3, R-4, and R-5) is recommended for mechanical electronic applications requiring high mechanical strength, impact resistance, and insulating characteristics. All other compounds contain various mineral fillers in addition to glass-fiber reinforcement. Ryton R-7 and R-8 are suitable for electrical applications requiring high arc resistance and low arc tracking. The R-10 series of pigmented compounds includes several grades suitable for support of current-carrying parts in electrical components. PPS is essentially transparent to microwave radiation, so the R-11 series is suited specifically for microwave ovenware and appliance components.

Unreinforced PPS resins are also available as powders for slurry coating and electrostatic spraying. The resin coatings are suitable for food-contact applications as well as for chemical-processing equipment.

The injection-moldable PPS compounds require processing temperature of 600 to 650°F. Mold temperatures can range from 100 to 275°F to control the crystallinity. Cold-molding parts deliver optimum mechanical strength, and hot-molded highly crystalline parts provide optimum dimensional stability at high temperatures.

PPS is also available in long-fiber-reinforced forms. One type, called stampable sheet, contains fiber mat reinforcement for processing by compression molding. The other form contains reinforcement, and is designed for laminating and thermoforming. Reinforcement in both forms can be glass or carbon fiber.

Properties: Most PPS compounds are used for their combination of high-temperature stability, chemical resistance, dimensional reliability, and flame retardance. The compounds all

PPS compounds

ASTM or UL test	Property	GLASS-REINFORCED				GLASS AND MINERAL FILLED		
		R-3	R-4	R-5	R-7	R-8	R-9	R-10
	PHYSICAL							
D792	**Specific gravity**	1.57	1.67	1.72	1.9	1.8	1.9	2.0
D570	**Water absorption,** 24 h 1/8 in. thk. (%)	0.05	0.05	0.05	0.03	0.03	—	0.07
	MECHANICAL							
D638	**Tensile strength** (psi)	16,000	17,500	19,000	14,000	10,750	11,000	10,000-13,500
D638	**Elongation** (%)	1.0	0.9	0.8	0.7	0.5	0.5	0.7
D790	**Flexural strength** (psi)	19,500	26,000	28,000	23,000	14,800	17,500	16,000-20,000
D790	**Flexural modulus** (10^5 psi)	14	17	21	24	22	21	20
D256	**Impact strength,** Izod (ft-lb/in. of notch)							
	Notched	1.0	1.3	1.3	1.0	0.6	0.7	0.7-1.0
	Unnotched	3.3	4.5	5.0	3.5	1.9	2.1	1.7-2.8
D785	**Hardness,** Rockwell R	120	123	123	121	121	—	120
	THERMAL							
C177	**Thermal conductivity** (Btu-in./in.-ft^2-°F)	—	2.0	—	4.0	—	—	3.9
D696	**Coef of thermal exp** (10^{-5} in./in.°F)	1.7	1.6	1.5	1.1	1.6	1.1	1.2
D648	**Deflection temperature** At 264 psi (°F)	500	500	500	500	500	500	500
D2863	**Oxygen index** (%)	46	47	48	53	50	45	53
UL 946B	**Temperature index** (°C)	200/220	200/220	200/220	200/220	200/220	200/240	200/240
UL 94	**Flammability rating**	V-0	V-0/5-V	V-0	V-0	V-0/5-V	V-0	V-0/5-V
	ELECTRICAL							
D149	**Dielectric strength** (V/mil)	450	450	420	340	340	400	320-400
D150	**Dielectric constant**							
	At 1 kHz	3.9	3.9	4.0	5.1	4.6	4.6	4.7
	At 1 MHz	3.8	3.8	3.9	4.6	4.3	4.5	4.5
D150	**Dissipation factor**							
	At 1 kHz	0.002	0.002	0.002	0.058	0.017	0.014	0.009
	At 1 MHz	0.0014	0.0014	0.0014	0.0088	0.016	0.0072	0.007
D257	**Volume resistivity** (ohm-cm)	1×10^{16}	1×10^{16}	1×10^{16}	5×10^{15}	2×10^{15}	6×10^{15}	6×10^{15}
D495	**Arc resistance** (s)	10	34	128	167	182	180	116-182
UL 746A	**Arc-tracking rate** (in./min)	11.3	7.1	6.3	0	0	0	0-0.6

Test specimens prepared using hot (275°F) mold. R-10 Values listed cover a series of compounds.

have excellent stability at very high temperatures. UL temperature index is 200 to 240°C, depending on compound, thickness, and end use. In short-term excursions, the compounds have heat-deflection temperatures of 500°F or higher, depending on the crystallinity of the molding. Mechanical strength of the compounds remains high at high temperatures. For example, the flexural modulus of Ryton R-4 is as high at 500°F as that of ABS at room temperature.

PPS has excellent resistance to a broad variety of chemicals, even at high temperatures. In fact, the resin has no known solvent below 400°F. The resins are flame-retardant without additives (UL94V-0/5). The oxygen index of the resin is 44, and indexes of the compounds range from 47 to 53. Because flame retardance is inherent, regrind is as flame resistant as virgin material.

Mechanical properties of the various PPS compounds are tailored for target applications. The balance of properties can be controlled by the degree of crystallinity of a molded part. Amorphous moldings have optimum mechanical strength at room temperature, and crystalline moldings deliver optimum dimensional stability at high temperatures.

Applications: Principal applications of injection-molded PPS compounds are electrical/electronic and industrial mechanical equipment. The glass-reinforced compounds are used in telecommunications, computer, and electronic components such as connectors, coil forms, and bobbins. Glass-reinforced and mineral-filled compounds are better suited for higher power uses and structural components such as motor-brush holders requiring UL direct-support rating.

PPS moldings are widely used in chemical and petroleum-processing equipment such as submersible centrifugal, vane, and gear-type pumps needing high strength and chemical resistance at high temperatures.

Many underhood automotive components of PPS are in commercial production. Here, selection of PPS is based heavily on its resistance to the corrosive effects of hot exhaust gases, ethylene glycol, gasoline, and other automotive fluids.

In handheld and small appliances, heat-resistant PPS compounds offer the added feature of color. Typical applications include hair dryers, other personal-care items, and small cooking appliances. Blends with PTFE are also used for release coatings on molds, cookware, and industrial containers.

Components molded from PPS stampable sheet include housings for industrial pumps and meters, pipe fittings, aircraft seat backs and interior panels, and commercial heat exchangers.

Polystyrene

Noted for its sparkling clarity, hardness, ease of processing, and excellent colorability, polystyrene is a low-cost amorphous thermoplastic that often competes favorably with higher-priced resins. PS is available in a wide range of grades for injection molding, extrusion, and foam molding. Modifications to the basic, general-purpose PS resin include grades for high heat, and for various degrees of impact resistance. Clarity and gloss are reduced, however, in the impact grades.

Polymers in the styrene family include ABS and SAN, described in another chapter, and the styrene-maleic anhydride (SMA) copolymers. Structural characteristics of these resins are similar, but the SMA resins have the highest heat resistance.

Expandable polystyrene (EPS) is a specialized form of the resin used to make low-density (0.75 to 10.0 lb/ft) foam shapes and blocks. These materials are suited for thermal insulation and energy absorption. Copolymers of polystyrene formulated into EPS-type foamable resins provide improved heat tolerance, solvent resistant, or cushioning.

Expandable PS foams are produced in a two-stage process. The resin particles are first expanded to the density required in the finished item while remaining as discrete particles. In the second step, the foamed particles are placed in a vented mold of the final shape. Steam is forced into the mold, heating the particles by direct contact and causing them to expand and fuse together to form a void-free, dry foam part. Pressures in the process are usually below 50 psi, allowing the use of relatively low-cost aluminum tooling.

Properties: Unmodified polystyrene is rigid and brittle, has moderate strength, and is crystal clear. Impact strength is increased significantly by blending the polymer with rubbers such as polybutadiene.

Heat resistance is low compared to that of most thermoplastics; maximum recommended continuous-service temperature is well under 200°F. Electrical properties are good at room temperature and are affected only slightly by higher temperatures and varying humidity conditions.

Polystyrene is soluble in most aromatic and chlorinated solvents. It is insoluble in alcohols such as methanol, ethanol, normal heptane, and acetone. Most foods, drinks, and household fluids that have no effect on polystyrenes, but the resins are attacked by citrus-fruit-rind oil, gasoline, turpentine, and lacquer thinner.

Applications: General-purpose polystyrenes are used for knobs, light shields, disposable beverage glasses, serviceware, and packaging items. High-heat formulations are found in radio and TV cabinets, tape reels, and appliance parts. Impact grades are used in appliances, toys, housewares, and specialty items. Structural-foam polystyrene is used in wood-replacement products such as "carved" components for furniture and, in extruded form, trim strips and baseboards for residential and mobile-home use.

EPS foams are used for heat insulation in the building industry and in

Polystyrene

		POLYMERS		COPOLYMERS		
ASTM or UL test	**Property**	**General purpose**	**Impact modified**	**Crystal clear**	**Impact modified**	**Glass reinforced***
D792	**Specific gravity**	1.04-10.9	1.03-1.10	1.08-1.10	1.05-10.8	1.13-1.22
D792	**Specific volume** (in.^{3}/lb)	26.0-25.6	28.1-25.2	—	—	—
D570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.03-0.10	0.05-0.6	0.1	0.1	0.08
	MECHANICAL					
D638	**Tensile strength** (psi)	5,000-12,000	1,500-7,000	7,000-7,600	4,800-7,200	10,500-12,500
D638	**Elongation** (%)	0.5-2.0	2-60	1.4-1.7	2.0-20.0	1.3-2.0
D638	**Tensile modulus** (10^5 psi)	4.0-6.0	1.4-5.0	4.4-4.7	2.8-4.2	6.3-10.0
D790	**Flexural strength** (psi)	8,000-17,000	3,000-12,000	12,000-12,600	8,500-12,200	12,200-19,700
D790	**Flexural modulus** (10^5 psi)	4.0-4.7	1.5-4.6	4.6-4.9	3.2-4.5	5.5-9.8
D256	**Impact strength,** Izod (ft-lb/in. of notch)	0.2-0.45	0.5-4.0	0.3-0.5	0.5-4.4	1.8-2.6
D785	**Hardness,** Rockwell M	65-80	10-90	108	80	101
	THERMAL					
C177	**Thermal conductivity** (Btu-in./hr-ft°F)	2.4-3.3	1.0-3.0	2.4-3.3	1.0-3.0	—
D696	**Coef of thermal expansion** (10^{-5} in./in.-°F)	3.3-4.4	1.9	3.5-3.7	3.5-3.7	2.0-2.2
D648	**Deflection temperature** (°F)					
	At 264 psi	190-220	160-200	235-249	235-249	235-260
	At 66 psi	180-230	180-220	—	—	—
UL 94	**Flammability rating†**	HB	HB	HB	HB	HB
	ELECTRICAL					
D149	**Dielectric strength** (V/mil) Short time, ⅛-in. thk	500-700	300-600	500-700	300-600	—
D150	**Dielectric constant** At 1 kHz	2.40-2.65	2.4-4.5	—	—	—
D150	**Dissipation factor** At 1 kHz	0.0001-0.0003	0.0004-0.0020	—	—	—
D257	**Volume resistivity** (ohm-cm) At 73° F, 50% RH	10^{17}-10^{19}	10^{16}	—	—	—
D495	**Arc resistance** (s)	60-135	20-100	95	95	—
	OPTICAL					
D542	**Refractive Index**	1.60	—	1.59	—	—
D1003	**Transmittance** (%)	87-92	35-57	92	—	—

*10-20% †V-2, V-1, and V-0 grades are also available.

appliances. The shock-absorbing characteristics make them useful for packaging products ranging from bottled cosmetics to electronics equipment. Foam blocks are used for protecting bumpers of new cars in shipment. Light weight and moisture resistance of the foam make it ideal for drinking cups and flotation products.

Molded EPS shapes are also used as expendable patterns for metal castings made by the "lost-foam," or "full-mold," process.

Styrene copolymers: A higher heat resistance distinguishes the styrene-maleic anhydride copolymers from their base styrenic and ABS families. The SMA copolymers have high molecular weights (200,000 to 250,000 average), and are processed by injection molding, extrusion, injection-blow molding, and extrusion-blow molding.

These resins have excellent melt rheology and flow characteristics at melt temperatures of 400 to 550°F and with mold temperatures of 120 to 150°F. Styrene copolymers set up rapidly and provide fast molding cycles. Processibility of both crystal-clear and impact-modified copolymers is excellent. Heat properties, processing ease, and costs provide an excellent balance for cost-effective applications.

Crystal-clear SMA resins can be pigmented to produce a wide range of transparent, translucent, or opaque colors. Best results are obtained with master batches or concentrates using SMA or polystyrene as the carrier resin.

Properties: Heat resistance of SMA resins is typically 20 to 50°F greater than that of polystyrene, SAN, and ABS. Glass-fiber reinforcement further improves thermal properties, rigidity, flexural properties, dimensional stability, and impact strength. Typical glass content in these materials is 10 to 20%, depending on end-use requirements.

Both dry blends and precompounded glass-reinforced materials are available. These reinforced resins provide a cost-effective balance of thermal and structural properties and processibility. Both the crystal-clear and impact-modified grades meet FDA and DoA requirements for food-contact use. Flammability rating of the copolymers is UL94 HB.

Applications: Transparent, crystal-clear styrene copolymers are used in packaging, appliance, and houseware applications requiring water-white clarity and rigidity. Typical uses include: steam hair-curler covers, food-processor pushers, water tumblers, food basters, interior advertising signs, and decorative cosmetic packages.

Impact-modified styrene copolymers are used in automotive, advertising, appliance, and food-service applications. Typical uses are: home air-conditioning/heater grilles; automobile radio-speaker grilles, glovebox doors, console housings, heater ducts, instrument mounting supports, ashtray doors, and vent grilles; hospital food-service trays; cosmetic travel-mirror cases; and indoor lighted-sign displays.

Glass-reinforced SMA resins are used for electrical connectors and automobile consoles and instrument-panel retainers. One-piece or two-piece full-width retainers are injection molded, foamed and vinyl covered.

SMA-PC blends: Blends of styrene maleic anhydride copolymers and polycarbonate provide an excellent balance of processibility and heat resistance, impact strength, and ductility. Large parts can be molded with fewer gates and lower tonnage machines because of their processibility, and small parts can be molded with pinpoint gates without loss of impact strength.

Properties: Heat resistance and impact strength at room and low temperatures are the primary attributes of SMA-PC blends. Deflection temperature under load (⅛-in. bars) ranges from 226 to 242°F. Gardner and notched Izod impact-strength values are 480 in.-lb and 10 to 12 ft-lb. These blends are also compounded with glass-fiber reinforcement for improved flexural modulus and heat resistance.

Applications: Automotive uses of SMA-PC blends include air-conditioner/heater ducts and grilles, radio-speaker grilles, decorative trim panels, glove-box doors, instrument-cluster housings, consoles, exterior trim panels, and wheel covers. Nonautomotive applications include computer and mobile telephone housings, surgical appliances, hospital feed trays, camera components, and portable electric-tool housings. Grades that meet requirements for food-contact applications are available.

Polyurethane

Extremely wide variations in forms and in physical and mechanical properties are available in polyurethanes. Grades can range in density from 0.5 lb/ft^3 in cellular form, to over 70 lb/ft^3 in solid form, and in hardness from rigid solids at 85 Shore D to soft, elastomeric compounds.

Polyurethane polymers, produced by the reaction of polyisocyanates with polyester or polyether-based resins can be either thermoplastic or thermosetting. They have outstanding flex life, cut resistance, and abrasion resistance. Some formulations are as much as 20 times more resistant to abrasion than metals.

The noncellular grades — millable gums and viscous, castable, liquid urethanes — are elastomeric thermoset types, processed by conventional rubber methods. These are discussed in the chapter, *Thermoset rubber*. Grades processed by thermoplastic methods are covered in the chapter, *Thermoplastic elastomers*. This chapter discusses the cellular polyurethane materials.

Polyurethane foams are thermoset materials that can be made soft and flexible or firm and rigid at equivalent densities. These foams, made from either polyester or polyether-type compounds, are strong, even at low density, and have good chemical resistance. Polyether-based foams have greater hydrolysis resistance, are easier to process, and cost less. Polyester-based foams have higher mechanical properties, better oil resistance, and more uniform cell structure. Both types can be sprayed, molded, foamed in place, or furnished as sheets cut from slab stock — buns, 30 to 48 in. high, to 80 in. wide, and to 200 ft long.

A low-pressure molding process — reaction-injection molding (RIM) is used almost exclusively to produce urethane parts — some weighing as much as 100 lb. In the process, two or more highly reactive liquid systems are injected with high-pressure impingement mixing into a closed mold at low pressure, where they react to form a finished polymer. Depending on formulation, the polymer can be a rigid, integral-skin, microcellular urethane foam with a flexural modulus of over 100,000 psi, a soft, flexible elastomer with a flexural modulus as low as 7,000 psi, or a rigid structural foam having a density of 30 lb/ft^3. Cycle time is short; parts can be demolded in less than a minute.

Reinforcement in the form of milled glass fiber, glass flake, or mineral filler increases the stiffness, thermal properties, and dimensional stability of RIM parts. Maximum glass content in reinforced reaction-injection molding (RRIM) is about 25% — a limit determined by the increased viscosity with increasing glass. Natural color of unpigmented RIM urethane parts is tan.

Flexible foams: Glass-transition temperatures (the temperature at which an elastomeric material becomes stiff and brittle) of flexible foams is well below room temperature. The foams can be pigmented to any color but, regardless of pigmentation, they yellow when exposed to air and light. Some types of flexible foams are excellent liquid-absorbing media, and can hold up to 40 times their weight of water.

Polyether-type foams are not affected by high-temperature aging, either wet or dry, but UV exposure produces brittleness and reduces properties. In use, these foams are always covered with a fabric or other material.

Most solvents and corrosive solutions decrease tear resistance and tensile strength and cause swelling of flexible foams. Swelling is not permanent, however, if the solvent is removed and the foam dried. However, the foams can be destroyed by strong oxidizing agents and hydrolyzed in strong acids or bases. Generally, the polyether foams are more resistant to hydrolytic degradation; the polyester foams are more resistant to oxidative attack.

Applications for polyester flexible urethane foam include gasketing, air filters, sound-absorbing elements, and clothing interliners (laminated to a textile material). The polyether types are used in automobile and recreational-vehicle seats, carpet underlay, furniture upholstering, bedding, and packaging.

Rigid foams: Bases for rigid foams are polymers having glass-transition temperatures higher than room temperature. The cells of rigid foam are about the same size and uniformity as those of flexible foam, but rigid foams usually consist of 90% closed cells. For this reason, water absorption is low. Compressing the foam beyond its elastic limit damages the cellular structure.

Rigid foams are blown with either carbon dioxide or fluorocarbons. Gas generated by vaporization of fluorocarbons, entrapped in the closed cells, gives the foam a very low thermal conductivity of 0.11 to 0.14 Btu-in./h-ft^2-°F. Conductivity increases with age, however, to a constant value of about 0.16. Conductivity of CO_2-blown foam starts at about 0.22 Btu-in./h-ft^2-°F.

Properties of rigid foams vary with density and formulation. Compressive strength of a 2 lb/ft^3 foam is 30 to 40 psi for a polyether type and 25 to 40 for a polyester type (parallel to the direction of foam rise). The values increase in a 12 lb/ft^3 foam to 560 and 420 psi. Strengths are lower, by about 50%, in the direction perpendicular to foam rise.

Rigid urethane foams are used for thermal insulation of refrigerators, refrigerated trucks and railroad cars, cold-storage warehouses, and process tanks because of their low conductivity and high strength-to-weight ratio. Other applications include flotation devices, encapsulation, structural and decorative furniture components, and sheathing and roof insulation for buildings.

Integral-skin foam: Urethane foams that are formed with integral skins range from soft and flexible types to impact-absorbing grades and rigid foams used in structural parts. Color can be added, but since the foams yellow on aging, black is most practical for the surface color. If other colors are required, coatings are recommended. The tough, high-density, integral skin is formed against the mold surface and the low-density core is produced by a blowing agent — usually a fluorocarbon.

Self-skinning rigid polyurethane foams

ASTM test	Property	
	PHYSICAL	
D792	**Density** (lb/ft^3)	35-40
—	**Water absorption** (% by w)	<1
—	**Water-vapor permeability** (g/m^2-day)	<1
	MECHANICAL	
D638	**Tensile strength** (psi)	2,500-3,000
D638	**Elongation** (%)	8-9
D638	**Tensile modulus** (10^3 psi)	110-160
D790	**Flexural strength** (psi)	6,000-7,000
D790	**Flexural modulus** (10^3 psi)	120-170
D256	**Impact strength,** unnotched (ft-lb/in.^{2})	7-15
D785	**Hardness,** Shore D	75-85
	THERMAL	
C177	**Thermal conductivity** (Btu-in./h-ft^2-°F)	0.4-0.8
D696	**Coef of thermal expansion** (10^{-5} in./in.-°F)	4.5
—	**Specific heat** (cal/g)	0.33
	ELECTRICAL	
D149	**Dielectric strength** (kV/cm)	50-100
D150	**Dielectric constant** At 0.8 kHz	1.8
D150	**Dissipation factor** At 0.8 kHz	0.007
D257	**Volume resistivity** (ohm-cm) At 73°F, 50% RH	2×10^{14}

Elastomeric foams of this type are used in automotive bumper and fascia systems and, most recently (reinforced with milled-glass fibers), in fenders and other exterior body panels. The semirigid types are used in athletic protective gear, in automotive crash-protection areas, horn buttons, sun visors, and arm rests. Applications for the rigid structural foams include housings for computer systems, chair shells, furniture drawers, and sports equipment.

Polyvinyl chloride

Among the vinyl polymers and copolymers, the polyvinyl-chloride (PVC) thermoplastics are the most commercially significant. With various plasticizers, fillers, stabilizers, lubricants, and impact modifiers, PVC is compounded to be flexible or rigid, opaque or transparent, to have high or low modulus, or to have any of a wide spectrum of properties or processing characteristics.

PVC resin can also be chlorinated (CPVC) and it can be alloyed with other polymers such as ABS, acrylic, polyurethane, and nitrile rubber to improve impact resistance, tear strength, resilience, heat-deflection temperature, or processibility.

PVC compounds are processed by extrusion, injection molding, calendering, compression molding, and blow molding. PVC coatings are applied by fluidized-bed and electrostatic powder-coating methods. The resins are also used for dip molding and coating, in the form of plastisols and organosol dispersions or water dispersions (latexes). Cellular PVC products are made by introducing gas into the resin during molding or extrusion. Foams can be open or closed cell, and can be elastomeric or rigid, depending on plasticizer content.

PVC compounds can be made water-white in flexible compounds, very clear in rigid compounds, and they can be pigmented to almost any color.

Properties: With so many property variations attainable by compounding methods, no single compound can be considered typical of polyvinyl chloride. For example, creep rate of rigid compounds is so low and predictable that they can be used to make pressure pipe for water distribution; flexible compounds can be soft enough, yet impermeable, so that they are used for baby pants and for an excellent imitation suede, or they can be transparent, nontoxic, and tough enough to be used for mineral-water bottles.

Rigid PVC, sometimes called the "poor man's engineering plastic" is a hard, tough material that can be compounded to a wide range of properties. Noteworthy among its properties is low combustibility; it has high resistance to ignition and is self-extinguishing. It also provides good corrosion and stain resistance, thermal and electrical insulation, and weatherability. However, PVC is attacked by aromatic solvents, ketones, aldehydes, naphthalenes, and

Polyvinyl chloride

ASTM test	Property	Rigid	Flexible
	PHYSICAL		
D792	**Specific gravity**	1.30-1.58	1.20-1.70
D792	**Specific volume** (in.^{3}/lb)	20.5-19.1	—
D570	**Water absorption**, 24 h, ⅛-in. thk (%)	0.04-0.4	0.15-0.75
	MECHANICAL		
D638	**Tensile strength** (psi)	6,000-8,000	1,500-3,500
D638	**Elongation** (%)	50-150	200-450
D638	**Tensile modulus** (10^5 psi)	3.5-10	—
D790	**Flexural modulus** (10^5 psi)	3-8	—
D256	**Impact strength**, izod (ft-lb/in. of notch)	0.4-20.0	—
D785	**Hardness**, Shore	65-85D	50-100A
	THERMAL		
C177	**Thermal conductivity** (10^{-4} cal-cm/sec-cm^2-°C)	3.5-5.0	3.0-4.0
D696	**Coef of thermal expansion** (10^{-5} in./in.-°F)	1.2-5.6	3.9-13.9
D648	**Deflection temperature** (°F)		
	At 264 psi	140-170	—
	At 66 psi	135-180	—
	ELECTRICAL		
D149	**Dielectric strength** (V/mil)		
	Short time, ⅛-in. thk	350-500	300-400
D150	**Dielectric constant**		
	At 1 kHz	3.0-3.8	4.0-8.0
D150	**Dissipation factor**		
	At 1 kHz	0.009-0.017	0.07-0.16
D257	**Volume resistivity** (ohm-cm)		
	At 73° F, 50% RH	$>10^{16}$	10^{11}-10^{15}
D495	**Arc resistance** (s)	60-80	—

some chloride, acetate, and acrylate esters. Some impact modifiers used in rigid PVC reduce chemical resistance. In general, normal-impact grades have better chemical resistance than the high-impact grades.

Most PVC compounds are not recommended for continuous use above 140°F. Chlorination increases heat-deflection temperature, flame retardancy, and density and extends the continuous-use temperature to 176 to 212°F, depending on the amount of chlorination.

Applications: Products such as pipe, conduit, residential siding, and window frames are extruded from rigid polyvinyl chloride. Cellular rigid extrusions are replacing wood as moldings and trim components because they are easily installed. Injection-molded rigid PVC products include pipe fittings, housings for appliances and portable power tools, automotive kick pads, battery cases, electrical fittings, and conduit boxes.

Flexible compounds are used for wire and cable insulation because of their insulation properties, low combustibility, low cost, and good flexibility over a wide temperature range. Flexible film and sheet is used in upholstery, wall coverings, shower curtains, and clothing. Other applications include weather stripping, refrigerator gaskets, and automotive upholstery, trim, bumper strips, and roof tops. Flexible dip-molded parts include ductwork, electrical outlet covers, handle grips, and protective boots.

Structural foam

Extending the size capabilities of molded parts beyond the limits of conventional injection molding is one of the main advantages of structural-foam molding. While injection moldings are usually referred to in terms of ounces and inches, foam moldings usually involve pounds and feet, despite the fact that foam density is much lower. Parts weighing 50 lb are not uncommon by low-pressure structural-foam methods, and some molders can produce 100-lb parts in a single shot.

Foam processing: Although SF parts are produced by several different methods, all systems disperse a gas into the polymer melt during processing, either by adding a chemical blowing agent to the compound or by inducing a gas directly into the melt. The gas creates the cellular core structure in the part. Regardless of the type or form of foaming agent used or when it is added to the melt, structural-foam processes are classified as either low-pressure or high-pressure methods. Such a classification relates directly to size range, surface finish, economics, and properties of the molded part.

Low pressure, or short-shot, conventional SF processing methods are the most commonly used because they are the simplest and best suited for economical production of large, three-dimensional parts. In this process, a controlled mixture of resin and gas is injected into a mold creating a low cavity pressure — from 200 to 500 psi. The mixture only partially fills the mold, and the bubbles of gas, having been at a higher pressure, expand immediately and fill the cavity. As the cells collapse against the mold surface, a solid skin of melt is formed over the rigid, foamed core.

Skin thickness is controlled by amount of melt injected, mold temperature, type and amount of blowing agent, and temperature and pressure of the melt. With the use of multiple injection nozzles, extremely large parts can be molded; alternatively, several parts of varying sizes can be molded simultaneously in multicavity molds. Standard nominal wall thickness is ½ in.

A variation of the low-pressure method is the gas counter-pressure technique. Originating in Europe, proprietary systems are now used in the U.S. In this method, a sealed mold is pressurized to 400 to 500 psi with an inert gas — enough pressure to suppress foaming as the resin enters the mold. After the measured shot is injected, mold pressure is released, allowing the instantaneous foaming to form the core between the already-formed solid skins.

Another process variation, coinjection, involves the separate injection of two compatible resins. First, a solid resin is injected to form the solid, smooth skin against the mold surfaces. Then, the second material, a measured short shot containing a blowing agent, is injected to form the foamed part interior. The core material is usually a lower-cost resin than the skin material.

High-pressure, expandable-mold, structural-foam molding is closer to conventional injection molding. The heating melt (with a blowing agent) is injected into the mold, creating cavity pressures of between 5,000 and 20,000 psi. The mold is entirely filled, and the pressure prevents any foaming from occurring while the skin portion solidifies against the mold surfaces.

At this point, the method departs from conventional injection molding. Mold pressure must be reduced and space provided to allow foaming to take place between the solid-skin surfaces. Depending on the type of equipment and size and configuration of the part, these two provisions are made either by withdrawing cores or by special press motions that partially open the mold halves.

Advantages: In addition to large size capability and low-density structure, structural foam parts offer high stiffness-to-weight advantages. A 25% increase in wall thickness (over that of a solid section) can provide twice the rigidity — at equal weight — of a solid part. Strength-to-weight ratios of foamed sections can be two to five times those of structural metals. Foamed parts made by any of the various methods are relatively stress-free because the foaming is done at a low pressure. For the same reason, sink marks do not occur in foamed parts behind ribs or at wall intersections.

Tooling for low-pressure structural-foam molding is generally less expensive than that for injection molding because the low pressure permits the use of lighter-weight mold materials. Tooling for high-pressure systems is more expensive than for conventional molding because of the special tooling motions involved to accommodate the foaming cycle.

Limitations: Surface finish is the most apparent difference in low-pressure structural-foam parts, compared with conventional moldings. Part surfaces have a characteristic swirl pattern caused by the blowing agent, some of which becomes trapped between the mold surface and the skin of the part. The swirl pattern is both visual and tactile; surface roughness can be as much as 1,000 μin. Parts that require smooth, finished surfaces require secondary operations, usually sanding, filling, and painting.

The principal process variables that control the swirl pattern are mold temperature, melt temperature, injection rate, and the nature and concentration of the blowing agent. Control of these variables can produce foamed parts with surfaces that replicate any mold surface, smooth or patterned. But this improvement is not achieved without trade-offs: Changes involve slower injection rates, heating and cooling of the mold, and other alterations that increase mold costs.

Parts produced by gas counter-pressure molding have a significantly reduced swirl pattern because the foaming gases are kept in solution until the solid skin is formed against mold surfaces. Surfaces of coinjected parts are comparable to those of solid, injection-molded parts.

Surfaces of parts made by the high-pressure processes are comparable to those of injection-molded parts because the surface of the melt in contact with the mold solidifies while under pressure. But such parts have a "witness line," which has the appearance of a wide parting line at the edges — where the mold opening made provision for foaming. Such areas may require touching up.

Another limitation of high-pressure foam molding is part size and shape. The high pressures and the cost of tools limit these systems to much smaller parts than can be molded economically by low-pressure systems. Most high-pressure parts are relatively flat.

Materials and applications: Most widely used of the resins for structural-foam parts are the styrenes. Polystyrenes are used mainly in wood-replacement applications — furniture, building panels, door and window frames, tote boxes, pallets, and similar products. Other resins used in large-volume foamed parts are polypropylene, polyurethane (thermoset), polyethylene, PVC, and ABS. Also available in formulations for foam molding are engineering thermoplastics such as nylon, polycarbonate, modified polyphenylene ether, polyester, acrylic-styrene-acrylonitrile, polysulfone and thermoplastic elastomers and alloys. Some resins are also available in glass-reinforced formulations.

Applications for structural-foam parts molded from the engineering resins extend beyond the wood-replacement products. They include satellite dishes, business-machine and computer housings and panels, processing tanks and housings, material-handling pallets and totes, underground utility boxes, and automotive components replacing die castings and glass-reinforced injection-molded components.

Sulfone polymers

Sulfones are amorphous engineering thermoplastics noted for high heat-deflection temperatures and outstanding dimensional stability. These strong, rigid polymers are the only thermoplastics that remain transparent at service temperatures as high as 400°F.

The three commercially important resins in the sulfone family are polysulfone (Udel), polyarylsulfone (Radel), both produced by Amoco Performance Products Inc. and polyethersulfone (Victrex), produced by ICI Americas Inc. These materials are claimed to offer the highest performance profiles of any thermoplastics processible on conventional screw-injection and extrusion machinery. Processing temperatures, however, are higher than those of other thermoplastics; the sulfones are processed on equipment that can generate and monitor stock temperatures in the range of 650 to 720°F.

Natural color of the sulfone resins is transparent light amber. Continuous use in air or in steam at rated temperature does not cloud, craze, or otherwise destroy their transparency. These resins are also available in opaque colors and in mineral-filled and glass-reinforced compounds, which provide improved strength, stiffness, and thermal stability.

Properties: Heat resistance is the outstanding performance characteristic of the sulfones. Service temperature is limited by heat-deflection temperature, which ranges from 345 to 400°F. A high percentage of physical, mechanical, and electrical properties is maintained at elevated temperatures, within limits defined by the heat-deflection temperatures. For example, the flexural modulus of molded parts remains above 300,000 psi at service temperatures as high as 320°F. Even after prolonged exposure to such temperatures, the resins do not discolor or degrade. Thermal stability and oxidation resistance are excellent at service temperatures well above 300°F.

Heat aging of the polymers increases tensile strength, heat-deflection temperature, and modulus of elasticity appreciably. However, prolonged heat aging (about a year) decreases toughness, tensile strength, and elongation. Unnotched specimens of the sulfones are extremely tough and do not break in standard impact tests.

Electrical insulating properties are generally in the mid-range among those of other thermoplastics, and they change little after heat aging at the recommended service temperatures. Dissipation factor and dielectric constant — and thus, loss factor — are not affected significantly by increased temperature or frequency.

Creep of the sulfones, compared with that of other thermoplastics is exceptionally low at elevated temperatures and under continuous load. For example, creep at 210°F is less than that of acetal or heat-resistant ABS at room temperature. This excellent dimensional stability qualifies the sulfone resins for precision-molded parts.

The hydrolytic stability of these resins makes them resistant to water absorption in aqueous acidic and alkaline environments. The combination of hydrolytic stability and heat resistance results in exceptional resistance to boiling water and steam, even under autoclave pressures and cyclic exposure of hot to cold and wet to dry.

The sulfones also share a common drawback: They absorb ultraviolet rays, giving them poor weather resistance. Thus, they are not recommended for outdoor service unless they are painted, plated, or UV stabilized.

Applications: The three sulfone resins are used in similar applications differing principally by the service temperature involved. Molded components include coil bobbins, multipin connectors, integrated-circuit carriers, power-module housings, hair-dryer grilles, hot-water valves, and business-machine brackets. Glass-reinforced grades are used in automotive underhood parts such as switch housings and relay bases.

Molded sulfone parts are sterilizable by wet or dry heat or by gases. Applications are in medical instruments, respiration apparatus, filtration membranes, and medical implants. Food applications.

Polyether sulfone is also available as a film (ICI Films' Stabar) that offers the same high-temperature stability, chemical resistance, and electrical properties of molded PES components. Its low flammability and low smoke evolution during burning qualify Stabar film for use in aircraft interiors, power-module housings, and medical equipment. Other applications include xerographic transparencies, capacitor film, and flexible printed circuitry. ■

Technical assistance for the **Plastics** section was provided by: **Allied Signal Engineered Plastics,** Morristown, NJ, Engineering films, Nylon; **American Cyanamid Co.,** Wayne, NJ, Amino; **Amoco Performance Products Inc.,** Ridgefield, CT, Liquid-crystal polymers, Polyamide-imide, Sulfone polymers; **Arco Chemical Co.,** Philadelphia, PA, Polyolefins, Polystyrene; **Atochem Inc.,** Glen Rock, NJ, Fluoroplastics, Nylon; **Ciba-Geigy Corp.,** Hawthorne, NY, Epoxy; **DSM Engineering Plastics,** Reading, PA, Nylon; **Du Pont Co.,** Wilmington, DE, Acetal homopolymer, Acrylic, Fluoroplastics, Nylon, Polyester, Polyimide, Polyolefins; **Eastman Chemical Products Inc.,** Kingsport, TN, Cellulosics; **FMC Corp.,** New York, NY, Allyl; **GE Plastics,** Pittsfield, MA, ABS/SAN, Polyphenylene ether, Polycarbonate, Polyester, Polyetherimide, Structural foam; **BF Goodrich Co.,** Avon Lake, OH, PVC; **Hercules Inc.,** Wilmington, DE, Polyolefins; **Hoechst Celanese,** Chatham, NJ, Acetal copolymers, Liquid-crystal polymers, Polybenzimidazole, Polyolefins, Polystyrene; **ICI Films Inc.,** Wilmington, DE, Engineering films, Polyetheretherketone, Polyester, Polyimide, Sulfone polymers; **Mobay Chemical Corp.,** Pittsburgh, PA, Polycarbonate, Polyurethane; **Pennwalt Corp.,** Philadelphia, PA, Fluoroplastics; **Phillips Chemical Co.,** Bartlesville, OK, Polyphenylene sulfide; **Polymer Corp.,** Reading, PA, Nylon; **Rhone-Poulenc Inc.,** Monmouth Junction, NJ, Polyimide; **Rogers Corp.,** Rogers, CT, Allylic, Phenolic; **Rohm & Haas Co.,** Philadelphia, PA, Acrylic.

Sulfone polymers

ASTM test	Property	Property sulfone	Polysulfone	Polyether-sulfone
	PHYSICAL			
D792	**Specific gravity**	1.24	1.37	1.37
D570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.3	0.40	0.43
	MECHANICAL			
D638	**Tensile strength** (psi)	10,200	12,000	12,200
D638	**Elongation at break** (%)	50-100	40	40-80
D638	**Tensile modulus** (10^5 psi)	3.6	3.9	3.9
D790	**Flexural strength** (psi)	15,400	16,100	18,650
D790	**Flexural modulus** (10^5 psi)	3.9	4.0	3.8
D256	**Impact strength,** Izod (ft-lb/in. of notch)	1.3	1.6	1.6
D785	**Hardness,** Rockwell M	69	85	88
	THERMAL			
C177	**Thermal conductivity** (10^4 cal-cm/s-cm^2-°C)	6.2	—	3.2-4.4
D696	**Coef of thermal expansion** (10^{-5} in./in.-°F)	3.1	2.7	3.1
D648	**Deflection temperature** (°F) At 264 psi	345	400	398
D2863	**Oxygen index rating**	30	33	34-38
	ELECTRICAL			
D149	**Dielectric strength** (V/mil) Short time, (⅛-in. thk)	425	383	400
D150	**Dielectric constant** At 60 Hz to 1 MHz	3.07-3.03	3.51-3.54	3.5
D150	**Dissipation factor** At 60 Hz to 1 MHz	0.0008-0.0034	0.00171-0.00564	0.001-0.0035
D257	**Volume resistivity** (ohm-cm)	5×10^{16}	7.71×10^{16}	$10^{17} - 10^{18}$

Composites

Reinforcements allow designers to tailor materials that will meet specific requirements.

The concept of composites is not really new. Wood is considered to be a composite of cellulose fibers bonded by a matrix of natural polymers, mainly lignin. Egyptians reinforced mud with straw to make bricks. Concrete can be classified as a ceramic composite in which stones are dispersed among cement. And in the 1940s, short glass fibers impregnated with thermosetting resins, known as fiberglass, became the first composite with a plastic matrix.

Synergism enables reinforcing materials to improve properties of the matrix in composite materials. Designers now have the ability to tailor materials and their reinforcements to meet specific requirements. Composites also offer the designer a chance to build in only as much strength as they need where they need it.

All of these developments mean a larger and more complicated materials-choice menu. This diversity has made plastics applicable to a broad range of consumer, industrial, automotive, and aerospace products. It has also made the job of selecting the best materials from such a huge array of candidates quite challenging.

Optimizing materials

The conventional approach to design is to select a material and then optimize its configuration. Today, composite materials make it possible to optimize materials as well as their configurations.

The ideal way to develop a composite is to model and analyze it extensively

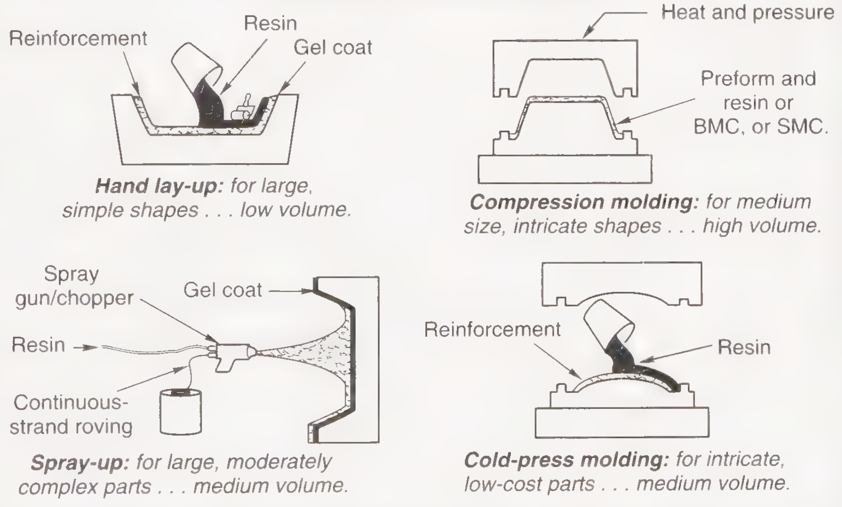
ADVANTAGES OF PREDISPERSED GLASS-REINFORCED COMPOUNDS

The bar chart shows the amount of mechanical work required to disperse glass fibers in a resin matrix to achieve an optimum property level in the molded part. Whatever amount of this work that is not done prior to the molding operation must be done in the injection-molding machine, indicated by the portions of the bars in color.

To minimize wear on the molding machine, it is desirable to do as much of this work as possible in the previous, extruder-mixing operations. Using predispersed pellets puts nearly all of the workload on the extruder, and very little on the molding machine. Another advantage of using predispersed pellets is that molding cycle times are shorter since only plasticizing — not dispersion as well — is done by the molding machine.

Predispersed pellets also provide higher and more consistent properties in the molded part than dry-blended or nondispersed materials, as shown in the normal-distribution curves. The property tested, in this case, is tensile strength.

THE PRINCIPAL FRP PROCESSES

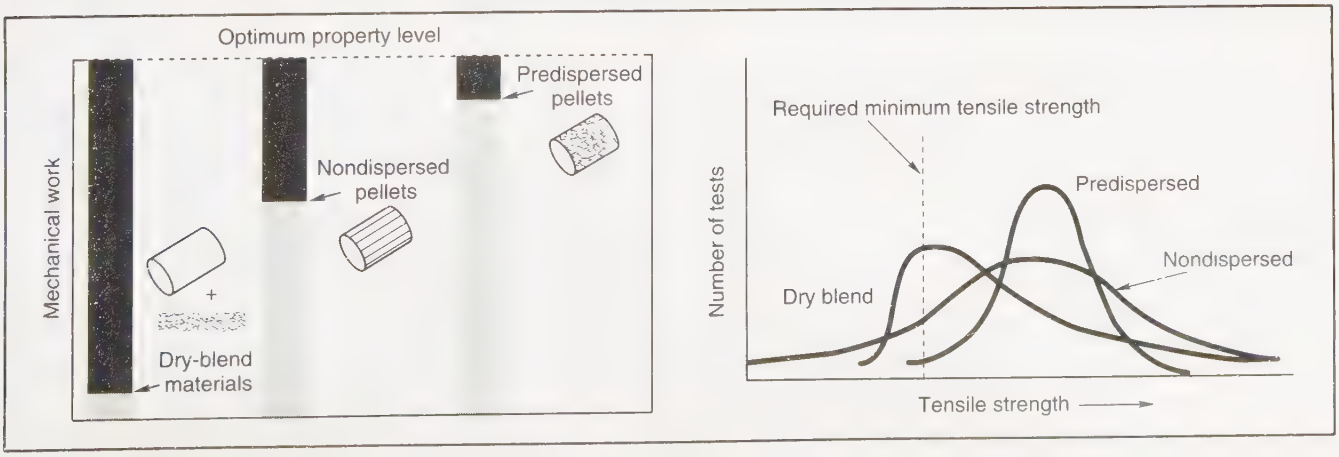


Hand lay-up: *for large, simple shapes . . . low volume.*

Compression molding: *for medium size, intricate shapes . . . high volume.*

Spray-up: *for large, moderately complex parts . . . medium volume.*

Cold-press molding: *for intricate, low-cost parts . . . medium volume.*



by computer before a prototype is built. But this is difficult because most computer programs were developed for metals and do not work well with composites.

Many new applications for composites are structural. Since the objective of structural parts generally is to maximize strength-to-weight ratios, a key design objective is to optimize configurations as well as materials. Computer assists in this area are also in a rudimentary stage of development.

After a design is defined, manufacturing is the next challenge. Building a single part normally is not technically taxing. The trick comes in fabricating composite parts reliably in mass production. Manufacturing operations tend to be expensive because fabrication is labor intensive, and the labor must be skilled.

The processes for fabricating composites also may produce built-in defects. For this reason, provisions for nondestructive testing (NDT) should go hand-in-hand with fabrication. Unfortunately, available methods for NDT often leave a lot to be desired.

All of these problems are being combated. Better guidelines are being developed to help designers select a composite and define its shape. Software is being developed to cope with the analytical complexities posed by composites and to help with the optimization process. Finally, major efforts are being exerted to automate fabrication processes and refine NDT operations.

DESIGN GUIDELINES

Rules about creep

- Increasing the load on a molded part increases the creep rate.
- Increasing the reinforcement level in a composite increases its creep resistance.
- Particulate-filled resins provide better creep resistance than unfilled resins, but they are less effective in this respect than fibrous reinforcements.
- Glass-fiber-reinforced amorphous-resin composites generally have greater creep resistance than crystalline resins containing the same amount of glass reinforcement.
- Carbon-fiber reinforcement is more effective in resisting creep than glass-fiber reinforcement.
- Flame-retardant additives affect different resins in different ways; each case should be evaluated separately.
- The effect of a flame-retardant additive on flexural modulus provides an indication of its effect on long-term creep.

Rules about fatigue endurance

- Fiber reinforcement provides significant improvement in fatigue life of a resin; carbon fibers improve this property more than glass fibers do.
- Effects of moisture in a service environment on fatigue endurance should be considered when hygroscopic materials such as nylon are to be used.
- For service involving a large number of fatigue cycles, crystalline-resin-based composites offer more predictable results than those based on amorphous resins because crystalline materials usually have a definite fatigue endurance limit.
- For optimum fatigue life in service involving both high stress and fatigue loading, reinforced high-temperature resins such as polyether sulfone, polyimide, and polyetheretherketone are recommended.

Thermoplastic composites

No longer is product design constrained to the property limits and performance characteristics of unmodified grades of resins. Thermoplastics that are reinforced with high-strength, high-modulus fibers provide dramatic increases in strength and stiffness, toughness, or dimensional stability. The performance gain of these composites usually more than compensates for their higher cost. Processing usually involves the same methods used for unreinforced resins.

Glass, mineral fibers: Glass fibers used in reinforced compounds are high-strength, textile-type fibers, coated with a binder and coupling agent to improve compatibility with the resin and a lubricant to minimize abrasion between filaments. Similar systems are used with mineral reinforcement. Glass-reinforced thermoplastics are usually supplied as ready-to-mold compounds. Molded products may contain as little as 5% and as much as 60% glass by weight. Pultruded shapes (usually using a polyester matrix) sometimes have higher glass contents. Most molding compounds, for best cost/performance ratios, contain 20 to 40% glass.

Practically all thermoplastic resins are available in glass-reinforced compounds. Those used in largest volumes are nylon, polypropylene, polystyrene, ABS, and SAN, probably because most experience with reinforced thermoplastics has been based on these resins. The higher performance resins — PES, PEI, PPS, PEEK, and PEK, for example — are also available in glass-fiber-reinforced composites, and some with carbon or aramid fibers as well.

Glass-fiber reinforcement improves most mechanical properties of plastics by a factor of two or more. Tensile strength of nylon, for example, can be increased from about 10,000 psi to over 30,000 psi, and deflection temperature to almost 500°F, from 170°F. A 40% glass-fortified acetal has a flexural modulus of 1.8×10^6 psi (up from about 0.4×10^6), a tensile strength of 21,500 psi (up from 8,800), and a deflection temperature of 335°F (up from 230°F). Reinforced polyester has double the tensile and impact strength and four times the flexural modulus of the unreinforced resin.

Also improved in reinforced compounds are tensile modulus, dimensional stability, hydrolytic stability, and fatigue endurance. Deformation under load of these stiffer materials is reduced significantly; deformation tests must be conducted at 4,000 instead of 2,000 psi stress (used for unreinforced materials) to produce usable results.

Fiber reinforcement of a resin always changes its impact behavior and notch sensitivity. The change may be in either direction, depending on the specific resin involved. But even when the change is an improvement, these properties may not be high enough for certain demanding applications. This need has led to the development of impact-modified compounds — specifically, nylon 6 and 6/6 alloys, a nylon 6/6 copolymer and a polypropylene copolymer — with up to 50% improvement over reinforced unmodified compounds. While the impact properties of a glass-reinforced compound are not always superior to those of the unreinforced compound, the reinforced modified compounds are always superior to the reinforced unmodified grades.

Molded glass-reinforced and mineral-reinforced plastics are used in a broad range of structural and mechanical parts. For example, glass-reinforced nylon, because of its strength and stiffness, is used in gears and automotive under-the-hood components, while mineral-reinforced nylon is used in housings and body parts because it is tougher and has low warpage characteristics. Polypropylene applications include automotive air-cleaner housings and dishwasher tubs and inner doors. Polycarbonate is used in housings for water meters and power tools. Polyester applications include motor components — brush holders and fans — high-voltage enclosures, TV tuner gears, electrical connectors, and automobile exterior panels. Camper tops, pallets, and hand luggage are typical applications of reinforced HD polyethylene.

Newest products in glass-reinforced compounds are the long-fiber materials. These compounds, available principally in a nylon 6/6 base resin, are produced by a pultrusion method. The injection-moldable pellets thus contain fully wetted fibers equal in length to the pellet — typically 0.400 in. This compares to 0.030 to 0.060-in. fiber lengths in conventional, short-fiber products. In fiber loads of 50% by weight, mechanical properties are improved dramatically over those of the short-fiber compounds. Long-fiber-reinforced compounds are available in the U.S. from ICI Advanced Materials, Polymer Composites Inc., and Dexter Composites.

Continuous-fiber glass-reinforced polypropylene is available in sheet form, for stamping or hot-flow forming of large, thin-wall parts such as automotive front-end retainer panels, oil-pans, fender liners, upper grille panels, and station-wagon load floors, and for lawn-mower shrouds, luggage, and housings and guards for farm equipment and snowmobiles. The product is marketed by Azdel Inc. The company also markets a glass-reinforced PET polyester sheet product and plans to add sheet materials based on other resin matrices.

Another new composite form is a sheet material in various thermoplastic matrix resins developed by Du Pont. Reinforcement is unidirectional but discontinuous glass, carbon, or aramid fibers.

Carbon fibers: Mostly developmental until a few years ago, carbon-fiber-reinforced compounds are now available in a number of thermoplastics, including nylon 6/6, polysulfone, polyester, polyphenylene sulfide, polyetherimide, polyetheretherketone, and ETFE and PFA fluorocarbons.

The carbon-fiber-reinforced materials, at two to four times the cost of comparable glass-reinforced thermoplastics, offer the ultimate in tensile strength (to 35,000 psi), stiffness, and other mechanical properties. Compared to the glass-reinforced materials these compounds (10 to 40% carbon) have a lower coefficient of expansion

What a difference glass makes

Base resin	Specific gravity	Mold shrinkage (in./in.)	Water absorption, 24-hr (%)	Tensile strength (10^3 psi)	Flexural modulus (10^6 psi)	Impact strength, Izod		Thermal expansion (10 ^{5} in./in.-°F)	Deflection temperature, 264 psi (°F)
						Notched (ft-lb/in.)	Unnotched (ft-lb/in.)		
ASTM test →	D792	D955	D570	D638	D790	D256		D696	D648
ABS	1.28	0.001	0.14	14.5	1.10	1.4	6-7	1.6	220
	(1.05)	(0.006)	(0.30)	(6.0)	(0.32)	(4.4)	(—)	(5.3)	(195)
Acetal	1.63	0.003	0.30	19.5	1.40	1.8	8-10	2.2	325
	(1.42)	(0.020)	(0.22)	(8.8)	(0.40)	(1.3)	(20)	(4.5)	(230)
ETFE	1.89	0.003	0.02	14.0	1.10	7.5	17-18	1.6	460
	(1.70)	(0.018)	(0.02)	(6.5)	(0.20)	(>40)	(—)	(4.0)	(160)
Nylon 6	1.37	0.004	1.1	23.0	1.20	2.3	20	1.7	420
	(1.14)	(0.016)	(1.8)	(11.8)	(0.40)	(1.0)	(—)	(4.6)	(167)
Nylon 6 alloy	1.37	0.004	1.1	22.0	1.00	3.2	22-24	1.7	415
Nylon 6/6	1.37	0.004	0.90	26.0	1.30	2.0	17	1.3	480
	(1.14)	(0.016)	(1.50)	(11.8)	(0.41)	(0.9)	(—)	(4.5)	(170)
Nylon 6/6 alloy	1.37	0.004	0.90	27.0	1.10	3.0	19-21	1.8	485
Nylon 6/6 copolymer	1.3	0.004	0.6	11.6	0.9	4.5	20-22	1.9	490
	(1.09)	(0.013-0.018)	(1.50)	(8.0)	(0.275)	(14)	(—)	(4.5)	(160)
Nylon 6/12	1.30	0.004	0.21	22.0	1.20	2.4	20	1.5	415
	(1.06)	(0.011)	(0.25)	(8.8)	(0.295)	(1.0)	(—)	(5.0)	(194)
Modified PPO	1.27	0.002	0.06	21.0	1.30	1.7	9-10	1.4	310
	(1.06)	(0.005)	(0.07)	(9.5)	(0.36)	(5.0)	(—)	(3.3)	(265)
Polycarbonate	1.43	0.001	0.07	18.5	1.20	3.7	17	1.3	300
	(1.20)	(0.006)	(0.15)	(9.0)	(0.33)	(2.7)	(60)	(3.7)	(265)
Polyester (PBT)	1.52	0.003	0.06	19.5	1.40	2.5	16-18	1.2	430
	(1.31)	(0.020)	(0.08)	(8.5)	(0.34)	(1.2)	(—)	(5.3)	(130)
Polyetherimide	1.51	0.002	0.18	28.5	1.25	1.7	16	1.1	420
	(1.27)	(0.006)	(0.25)	(15.2)	(0.48)	(1.0)	(25)	(3.1)	(392)
Polyetheretherketone	1.49	0.003	0.10	25.0	1.10	2.1	17	—	600
	(1.32)	(0.011)	(0.15)	(14.5)	(0.55)	(—)	(—)	(—)	(360)
Polyether sulfone	1.60	0.003	0.20	19.0	1.20	1.5	10	1.8	415
	(1.37)	(0.007)	(0.20)	(12.0)	(0.37)	(1.6)	(—)	(3.1)	(400)
Polyethylene (HD)	1.17	0.003	0.02	10.0	0.90	1.1	8-9	2.7	260
	(0.95)	(0.020)	(0.02)	(2.6)	(0.20)	(0.4)	(—)	(6.0)	(120)
PPS	1.56	0.002	0.04	20.0	1.60	0.3	1.4	1.1	500
	(1.34)	(0.010)	(0.05)	(10.8)	(0.60)	(3-4)	(8-9)	(3.0)	(280)
Polypropylene	1.13	0.004	0.03	9.8	0.80	1.6	5-6	2.0	295
Polypropylene	1.12	0.004	0.03	9.7	0.55	3.0	11-12	2.0	295
(chemically coupled)	(0.91)	(0.018)	(0.01)	(4.9)	(0.18)	(0.4)	(—)	(4.0)	(135)
Polystyrene	1.28	0.001	0.05	13.5	1.30	1.0	2-3	1.9	215
	(1.07)	(0.004)	(0.10)	(7.0)	(0.45)	(0.45)	(—)	(3.6)	(180)
Polysulfone	1.45	0.003	0.20	18.0	1.20	1.8	14	1.4	365
	(1.24)	(0.007)	(0.20)	(10.0)	(0.40)	(1.2)	(>60)	(3.1)	(340)
SAN	1.31	0.001	0.10	17.4	1.50	1.0	3-4	1.8	215
	(1.08)	(0.005)	(0.25)	(9.8)	(0.50)	(0.4)	(—)	(3.4)	(200)

Property values for the unreinforced resins are shown, for comparison, in parenthesis. Values given are representative; both higher and lower values may be obtained in commercially available resins and compounds. Values for the reinforced compounds are typical of 30% glass-reinforced formulations. Although there is no unnotched Izod test under ASTM D256, values from this test are often useful for material comparisons and selection.

The difference between unreinforced and aramid-reinforced thermoplastic resins

Base resin — ASTM test→	Specific gravity D792	Mold shrinkage (in./in.) D955	Water absorption, 24-hr (%) D570	Tensile strength (10^3 psi) D638	Flexural modulus (10^6 psi) D790	Impact strength, Izod Notched (ft-lb/in.) D256	Impact strength, Izod Unnotched (ft-lb/in.) D256	Thermal expansion (10^{-5}in./in.-°F) D696	Deflection temperature, 264 psi (°F) D648
Nylon 6/6	1.19	0.008	0.90	14.5	0.64	1.0	6.7	2.4	450
	(1.14)	(0.016)	(1.50)	(11.8)	(0.41)	(0.9)	(—)	(4.5)	(170)
Nylon 6/6 (15% aramid fiber, 10% PTFE)	1.29	0.008	0.6	(13.5)	0.55	1.0	8.5	3.1	465
Nylon 6	1.19	0.008	1.0	13.0	0.58	1.1	9.0	3.0	390
	(1.14)	(0.016)	(1.8)	(11.8)	(0.40)	(1.0)	(—)	(4.6)	(167)
Polyester (PBT)	1.33	0.013	0.06	9.5	0.60	0.8	9.0	3.0	380
	(1.31)	(0.020)	(0.08)	(8.5)	(0.34)	(1.2)	(—)	(5.3)	(130)
Polycarbonate	1.23	0.005	0.12	11.0	0.54	0.9	11	3.0	280
	(1.20)	(0.006)	(0.15)	(9.0)	(0.33)	(2.7)	(60)	(3.7)	(265)

Property values for the unreinforced resins are shown for comparison, in parenthesis. Values are typical; both higher and lower values may be obtained in commercially available resins and compounds. Values for the reinforced compounds are typical of 15% aramid-fiber-reinforced formulations. Although there is no unnotched test under ASTM D256, values from this test are often useful for material comparisons and selection.

and mold shrinkage, and improved resistance to creep and wear. Strength-to-weight ratios are also higher.

Carbon-fiber reinforcement also makes plastic compounds partially conductive. In compounds containing small amounts of carbon, this characteristic is useful for applications where static charges cannot be tolerated. Compounds containing higher percentages of carbon can be used for applications such as business-machine housings to shield the equipment from electromagnetic interference (EMI). Attenuation of electromagnetic radiation in carbon-fiber-reinforced nylon, for example, has been reported to be 36 to 40 dB in the frequency range from 50 kHz to 1 GHz.

Commercially available structural-carbon fibers are derived either from polyacrylonitrile (PAN) fibers or a special petroleum pitch. PAN-derived fibers have been available for several years and, for several of the lower modulus varieties, large databases have been developed through their use in aerospace programs. These fibers are generally selected for their high strength and efficient property translation into the composite.

The pitch-based fibers are newer and, while they are not as strong as the low-modulus PAN fibers, the ease with which they are processed into high-modulus components makes them attractive for stiffness-critical and thermally sensitive applications.

Pultrusion technology first provided long-glass fiber-reinforced composites with high-performance capabilities. Following close on the heels of this development are new long-carbon fiber-reinforced composites with even higher properties. Specifically, flexural and tensile moduli are the highest ever measured in discontinuous fiber-reinforced thermoplastic composites.

High stiffness-to-weight ratios and greater wear resistance allow these composites to compete against many metals. In addition, long-carbon composites are excellent candidates for applications requiring electrostatic dissipation and EMI shielding. Tests on some of the new composites have produced surprisingly high (60 dB and above) electromagnetic radiation attenuation values.

Aramid fibers: It would seem that aramid fibers, with greater specific strengths than steel or aluminum, would be an ideal reinforcement for thermoplastic resins. However, chopped aramid fibers do not compound as well as the conventional glass or carbon-fiber reinforcements. Proprietary sizing systems aid in wetting of the fiber, but extensive fiber damage results in properties for the composite that are less than spectacular.

On the plus side, aramid-fiber-reinforced composites have low warpage, excellent wear and abrasion resistance, as well as low coefficients of friction and low thermal expansion. In addition, the mechanical properties of the composites are relatively uniform in all directions.

Aramid-fiber-reinforced composites have been applied in applications such as chain snubbers and guides, where low wear and mating-surface wear are important. They have also been evaluated successfully in gears, bearings, compressor vanes, and pump impellers.

In the past, two drawbacks have made aramid-reinforced thermoplastic composites impractical. First was the difficulty of getting the chopped fiber dispersed in the resin because the high surface energy of the lightweight fibers inhibited wetting at the fiber/resin interface. This and the unusually low bulk density of commercially available aramid fiber did not allow processing in conventional compounding equipment. A second problem was the fiber damage that occurred, both during mixing and injection molding. Damage is usually severe because of the low compressive strength of aramid fiber.

The first of these problems have now been minimized, and fibers can be incorporated uniformly into a resin matrix. Consequences of the fiber damage show up, of course, as reduced properties which are similar to, or lower than, those of their glass-reinforced counterparts.

There is a silver lining, however, to the dark cloud of disappointing me-

Carbon fiber comparison

	PAN FIBERS					PITCH FIBERS		
	Nominal fiber modulus (10^6 psi)							
	30[a]	40[b]	40[c]	50[d]	70[e]	50[f]	75[g]	100+[h]
Fiber strength (10^3 psi)	500	820	>650	350	300	275	300	360
Tensile modulus (10^6 psi)	33	41	42	57	75	55	75	110
Composite strength (10^3 psi)								
Longitudinal	250	470	360	205	110	135	140	180
Transverse	10	10	10	5	4	5	5	3
Composite modulus (10^6 psi)								
Longitudinal	20	25	25	35	44	35	49	72
Transverse	2	2	1.5	1	4	1	1	1

a. Thornel 300 (Amoco)
b. Thornel T-40
c. Thornel T650/42
d. Thornel 50 PAN
e. Celanese GY-70
f. Thornel P-55 S
g. Thornel P-75 S
h. Thornel P-100 S

chanical properties. The aramid-reinforced composites have been found to have low warpage, good wear and abrasion resistance, low thermal expansion, and — most important of all — uniform mechanical and thermal properties in all directions. Conventional fiber-reinforced composites have lower shrinkage and higher strength and modulus in the flow direction. Not so with the aramid-reinforced materials. Properties, including mold shrinkage and thermal expansion, are nearly isotropic, regardless of flow pattern.

Internal lubrication: The first thermoplastics that were recognized for their inherent lubricity were nylon, acetal, and polytetrafluoroethylene (PTFE). These materials perform well, but for the more critical uses, their coefficients of friction may be too high, or wear may be too rapid.

The long and the short of carbon-fiber composites

	Tensile strength (10^3 psi)	Tensile modulus (10^6 psi)	Flexural strength (10^3 psi)	Flexural modulus (10^6 psi)	Compressive strength (10^3 psi)	Shear strength (10^3 psi)	Impact strength	
							Izod (ft-lb/in.)	Fall. dart (ft-lb)
Nylon 6/6								
Short fiber	40.0	4.7	53.0	3.4	29.0	14.5	1.6	6.6
Long fiber	42.0	6.2	64.5	4.8	31.5	19.8	2.9	7.1
Nylon 6/10								
Short fiber	35.0	3.6	47.0	2.95	—	—	2.0	—
Long fiber	37.8	4.7	59.0	3.7	—	—	3.0	—
Polycarbonate								
Short fiber	26.0	2.7	38.0	2.3	25.8	12.4	1.8	4.5
Long fiber	30.5	3.7	46.3	4.013	27.4	16.9	2.5	7.6

All composites contain 40 wt% carbon-fiber reinforcement.

The next generation of self-lubricated thermoplastics were formulations of various base resins that contained molybdenum disulfide, graphite, or PTFE particles to improve both lubrication and wear characteristics. Although wear resistance was indeed upgraded considerably, mechanical strength and dimensional stability of these compounds are often insufficient.

To minimize these deficiencies, reinforcing fibers of glass or carbon were added. The resulting composites are several times stronger than the unreinforced materials, and they are extremely stable in a wide range of service environments. But these materials too have a shortcoming: In service, a period of time is required for the internal lubricant to become exposed and to be burnished over the wear surfaces. During this run-in period, as a bearing or wear member is put into service, the unlubricated surfaces are in contact, and damage may occur.

Two approaches to eliminating these problems use silicone fluids to provide the lubrication function. Both of these, Migralube and Rimplast, are available as proprietary composites. Thermoplastic composites can also be internally lubricated with a variety of systems to improve wear resistance. PTFE and silicone, separately or in combination, provide the best improvements in wear characteristics. Graphite powder and molybdenum disulfide are also used, primarily in nylons. The PTFE lubricants are specially modified to enhance their lubricous nature in the compound. The optimum level of lubricating filler varies depending on filler type and resin, but typical ranges are:

PTFE	15-20%
Silicone	1-5%
PTFE/silicone	15-20%
Graphite	10%
MoS_2	2-5%

Addition of these lubricants further improves wear characteristics of good bearing materials such as nylon and acetal. The lubricants also allow the use of poor wearing, but high accuracy materials, such as polycarbonate, in gear or bearing applications. Lubricants can be used by themselves or in conjunction with glass or carbon-fiber reinforcements.

Polytetrafluoroethylene and silicone fluids; glass, aramid, and carbon fibers; and graphite powder are the primary reinforcements and lubricants used in internally lubricated composites. The composites are based on engineering resins for injection-molded wear and structural parts.

Polytetrafluoroethylene (PTFE) lubricants dispersed into a thermoplastic base resin greatly improve surface-wear characteristics. Molecular weight and particle size of the PTFE lubricant are designed to provide optimum improvements in wear, friction, and *PV* values for selected resin systems. PTFE has the lowest coefficient of friction (0.02) of any known internal lubricant. Its static coefficient of friction is lower than its dynamic coefficient, which accounts for the slip/stick properties associated with PTFE/metal sliding action. During the initial break-in period, the PTFE particles embedded in the thermoplastic matrix shear to form a high-lubricity film over the mating surface. The PTFE cushions asperities from shock and minimizes fatigue failure.

Silicone fluids are chosen for their ability to perform as boundary lubricants and for partial compatibility with a particular base resin. The silicone is sufficiently compatible with the base resin to form an alloy, yet incompatible enough to cause migration to the surface of the compound. The silicone moves to the surface of a molded or extruded part by two mechanisms: diffusion by random molecular movement, and exclusion from the matrix (migration) because of its limited compatibility. The result of the migratory action is a continuous generation of a silicone film, which serves as a boundary, or mixed-film lubricant.

Graphite powders are low-friction, high-temperature solids traditionally used to lubricate moving metal parts where boundary lubrication is required. Their ability to lubricate depends on their structure, purity, and particle size. Properly selected graphite powders can be extrusion compounded with a variety of thermoplastics to provide coefficients of friction and wear factors between those of the base resin and the PTFE/silicone-lubricated versions. An important use for graphite-lubricated thermoplastics is in components that operate in aqueous environments.

Reinforced and/or internally lubricated compounds are used in a variety of applications. Polycarbonate-based composites are used for gear and bearing surfaces where accuracy is important and chemical resistance is not a severe problem, such as in cameras and office equipment. Acetal and PPS-based compounds have found wide acceptance in hostile environments such as gasoline metering and pumping devices. Nylon composites are often chosen for certain harsh environments because of their excellent chemical resistance.

Thermoset composites

Ever since materials producers and compounders realized that material properties are improved significantly by the addition of a fiber or other reinforcing material, the field of composites has proliferated. The early high-performance thermoset-matrix materials were called advanced composites, differentiating them from the glass/polyester composites that were emerging commercially in the 1950s. The "advanced" term has come to denote, to most engineers, a resin-matrix material reinforced with high-strength, high-modulus fibers of glass, carbon, aramid, or even boron, and usually laid up in layers to form an engineered component. More specifically, the term has come to apply principally to epoxy-resin-matrix materials reinforced with oriented, continuous fibers of carbon or of a combination of carbon and glass fibers, laid up in multilayer fashion to form extremely rigid, strong structures.

Resin systems: More than 95% of thermoset composite parts are based on polyester and epoxy resins; of the two, polyester systems predominate in volume by far. Other thermoset resins used in reinforced form are phenolics, silicones, and polyimides.

Polyesters can be molded by any process used for thermosetting resins. They can be cured at room temperature and atmospheric pressure, or at temperatures to 350°F and under higher pressure. These resins offer a balance of low cost and ease of handling, along with good mechanical, electrical, and chemical properties, and dimensional stability.

Polyesters can be compounded to be flexible and resilient, or hard and brittle, and to resist chemicals and weather. Halogenated (chlorinated or brominated) compounds are available for increased fire retardance. Low-profile (smoother surface) polyester compounds are made by adding thermoplastic resins to the compound.

Polyesters are also available in ready-to-mold resin/reinforcement forms — bulk-molding compound (BMC), and sheet-molding compound (SMC). Bulk-molding compound is a premixed material containing resin, filler, glass fibers, and various additives. It is supplied in a doughlike, bulk form and as extruded rope.

Sheet-molding compound consists of resin, glass-fiber reinforcement, filler, and additives, processed in a continuous sheet form. Three types of SMC compounds are designated by Owens-Corning Fiberglas Corp., as random (SMC-R), directional (SMC-D), and continuous fiber (SMC-C). SMC-R, the oldest and most versatile form, incorporates short-glass fibers (usually about 1 in. long) in a random fashion. Complex parts with bosses and ribs are easily molded from SMC-R because it flows readily in a mold. SMC-C contains continuous glass fibers oriented in one direction, and SMC-D, long fibers (8 to 12 in. long), also oriented in one direction.

Moldings using SMC-C and SMC-D have significantly higher unidirectional strength but are limited to relatively simple shapes because the long-glass fiber cannot stretch to conform to a shape. These two types of SMC are usually, but not always, used in combination with SMC-R. Various combinations are available that contain a total of as much as 65% glass by weight. These materials are used for structural, load-bearing components.

High-glass-content sheet-molding compounds are also produced by PPG Industries, designated as XMC. These compounds contain up to 80% glass (or glass/carbon mixtures) as continuous fibers in an X pattern.

Epoxies are low-molecular-weight, syruplike liquids that are cured with hardeners to crosslinked thermoset structures that are hard and tough. Because the hardeners or curing agents become part of the finished structure, they are chosen to provide desired properties in the molded part. (This is in contrast to polyester formulations wherein the function of the catalyst is primarily to initiate cure.) Epoxies can also be formulated for room-temperature curing, but heat-curing produces higher properties.

Epoxies have outstanding adhesive properties and are widely used in laminated structures. The cured resins have better resistance than polyesters to solvents and alkalies, but less resistance to acids. Electrical properties, thermal stability (to 550°F in some formulations), and wear resistance are excellent.

Phenolics, the oldest of the thermoset plastics, have excellent insulating properties and resistance to moisture. Chemical resistance is good, except to strong acids and alkalies.

Reinforced phenolics are processed principally by high-pressure methods — compression molding and continuous laminating — because volatiles are condensed during the molding process. Recently developed injection-moldable grades, however, have made the processing of phenolics competitive with thermoplastic molding in some applications.

Silicones have outstanding thermal stability, even in the range of 500 to 700°F. Water absorption is low, and dielectric properties are excellent. Chemical resistance (except to strong alkalies) is very good.

Reinforcements: Glass is the most widely used reinforcing material in thermoset composites. Glass fiber, with a tensile strength of 500,000 psi (virgin fiber at 70°F), accounts for almost 90% of the reinforcement in thermosetting resins. Other reinforcements used are carbon, graphite, boron, and aramid (Kevlar) for high-performance requirements; glass spheres and flakes; and fibers of cotton, jute, and synthetic materials.

Glass fibers are available in several forms: roving (continuous strand), chopped strand, woven fabrics, continuous-strand mat, chopped-strand mat, and milled fibers (hammermilled through screens with openings ranging from 1/32 to ½ in.). The longer fibers provide the greater strength; continuous fibers are the strongest.

All forms of glass fibers are produced in the standard E-glass reinforcement type. Some of the higher strength forms are also available in S glass, which has a tensile strength about one-third higher than that of E-glass. Cost of S-glass is considerably higher. S-2 Glass, a product of Owens-Corning, is a variant of S-glass, having the same batch composition but without the rigid, military quality-control specifications. Properties are similar to those of S-glass; cost is between that of E and S-glass.

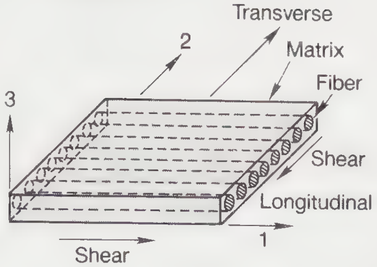
Carbon fibers in composites can be long and continuous, or short and fragmented, and they can be directionally or randomly oriented. In general, short fibers cost the least, and fabrication costs are lowest; but, as with glass, properties of resulting composites are lower than those obtainable with longer or continuous fibers.

Milled fibers are the shortest carbon fibers used for reinforcement. They range in length from 30 to 3,000 microns, averaging approximately 300 microns. Mean L/D ratio is 30. Short chopped fibers (about ½ in. long), with an L/D ratio of about 800, increase strength and modulus of a composite more than milled fibers do. Cost of a molding compound reinforced with ½-in. fibers is about twice that of one containing milled carbon fibers.

Long chopped fibers (to 2 in.) are often added to a thermosetting glass/

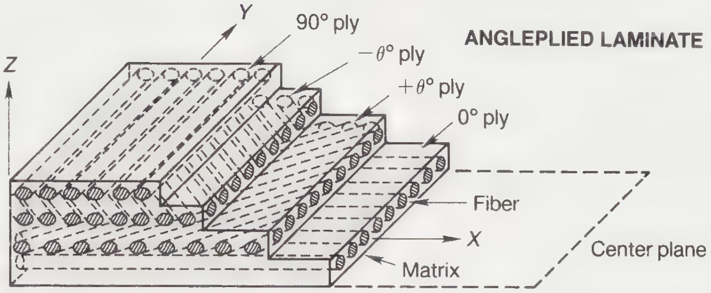
polyester sheet-molding compound to increase the stiffness of compression-molded parts. Continuous carbon fibers provide the ultimate in performance and/or weight reduction. Continuous fibers are available in a number of forms including yarns or tows containing 400 to 160,000 individual filaments; unidirectional, impregnated tapes up to 60 in. wide; multiple layers of tape with individual layers, or plies, at selected fiber orientation; and fabrics of many weights and weaves.

PLY AND LOADING TERMINOLOGY



Laminates are identified by the number of plies and fiber lay angle. Shorthand identification for the laminate here is $[90_1/-45_1/+45_1/0_1]$. *Plies are identified from the outside to inside and subscripts label the number of fiber layers for each angle. Often, a laminate repeats layer and angle sequence in reverse order. That is, the lays are symmetrical about a center plane. In this case, a subscript s is added to the notation and would read* $[90_1/-45_1/+45_1/0_1]_s$.

ANGLEPLIED LAMINATE



The outstanding design properties of carbon fiber/resin matrix composites are their high strength-to-weight and stiffness-to-weight ratios. With proper selection and placement of fibers, the composites can be stronger and stiffer than equivalent thickness steel parts and weigh 40 to 70% less. Fatigue resistance of continuous-fiber composites is excellent, and chemical resistance is better than that of glass-reinforced systems, particularly in alkaline environments. Like most rigid materials, however, carbon-fiber composites are relatively brittle. The composites have no yield behavior, and resistance to impact is low.

Thermal characteristics of carbon fibers are different from those of almost all other materials. Linear expansion coefficients range from slightly negative for 30-million-psi modulus fibers to approximately -1.3×10^{-6} in./in.-°F for the ultrahigh-modulus fibers. This property makes possible the design of structures with zero or very low linear and planar thermal expansion — a valuable characteristic for components in precision instruments such as telescopes and for the alignment requirements of aerospace antennas and similar critical parts. Transverse coefficients of expansion are quite different — typically 15×10^{-6} in./in.-°F.

The thermal conductivity of ultrahigh-modulus pitch-based carbon fibers exceeds that of copper. When density differences are considered, the specific conductivities can be as much as eight times that of copper.

Applications: Glass-reinforced polyester composites are used for automobile body panels, seats and panels for transit cars, boat hulls, bathroom shower-tub structures, chairs, architectural panels, agricultural seed and fertilizer hoppers, tanks, and housings for a variety of consumer and industrial products. Glass/epoxy applications include filament-wound pipe and tanks, and circuit boards.

Phenolic-matrix composites are used in printed-circuit boards, gears, and in insulators and other components for electrical equipment and appliances. Melamine applications include circuit boards, thermal and electrical insulation, and components requiring good chemical resistance. Silicones are chosen for service as electrical and thermal insulation, such as in circuit boards requiring maximum heat resistance.

The aircraft industry was quick to see the advantages of carbon/epoxy composites, which offered light weight, high strength and modulus, and — most important — excellent fatigue performance. Most engineering and manufacturing experience with these composites has been gained in developing military-aircraft components. While the manufacture of composite components is still highly labor intensive and expensive, the technology has advanced in recent years to improve production quality and speed with the use of systems such as automated tape laying.

Nevertheless, the high cost of carbon fibers and of processing the composites has limited most uses of carbon/epoxy composites to aerospace components — fuselage panels for military aircraft and cargo doors for the space shuttle, for example — and high-priced sports equipment — tennis-racquet frames, golf-club shafts, skis, and archery bows.

Laminated plastics

Laminated plastics are a special form of polymer-matrix composite consisting of layers of reinforcing materials that have been impregnated with thermosetting resins, bonded together, and cured under heat and pressure. The cured laminates, called high-pressure laminates, are produced in more than 70 standard grades, based on National Electrical Manufacturers Association (NEMA]) specifications.

Laminated plastics are available in sheet, tube, and rod shapes that are cut and/or machined for various end uses. The same base materials are also used in molded-laminated and molded-macerated parts. The molded-laminated method is used to produce shapes that would be uneconomical to machine from flat laminates, where production quantities are sufficient to warrant mold costs.

Strength of a molded shape is higher than that of a machined shape because the reinforcing plies are not cut, as they are in a machined part. The molded-macerated method is used for similar parts that require uniform strength properties in all directions.

Other common forms of laminated plastics are composite sheet laminates that incorporate a third material bonded to one or both surfaces of the laminate. Metals most often used in composites are copper, aluminum, nickel, and steel. Copper-clad sheets (one or both sides) for printed-circuit and multilayer boards comprise the largest volume of metal composite sheet laminates. Nonmetallics include elastomers, vulcanized fiber, and cork. Composite metal/plastic materials are also produced in rods and tubes.

Vulcanized fiber is another product

often classified with the laminated plastics because end uses are similar. Vulcanized fiber is made from regenerated cotton cellulose and paper, processed to form a dense material (usually in sheet form) that retains the fibrous structure. The material is tough and has good resistance to abrasion, flame, and impact.

Resins: Phenolics are the most widely used resin in laminated plastics. These low-cost resins have good mechanical and electrical properties and resistance to heat, flame, moisture, mild acids, and alkalies. Most paper and cloth-reinforced laminates are made with phenolics.

Polyesters are used for both electrical and mechanical service requiring moderate heat resistance. The resins are usually mineral filled to improve dimensional stability and flame retardancy and to reduce cost.

Malemine resins are used primarily in electrical-grade laminates because of their excellent resistance to arcing and tracking, high mechanical strength, and good resistance to alkalies.

Epoxies are recommended for applications requiring resistance to chemicals and humid environments. They have low moisture absorption and good dimensional stability, mechanical strength, bond strength, and fungus resistance.

Silicones, used primarily with glass-cloth reinforcement, have very high heat resistance (to 550°F). Laminates based on silicones have low moisture absorption, and they maintain their electrical properties over a wide range of service conditions.

Polyimide binders extend the use-temperature range of glass laminates upward. These resins can also withstand lengthy solder-bath exposure without blistering.

Reinforcements: Papers are the lowest-cost reinforcing materials used in making laminates. Types include kraft, alpha, cotton linter, and combinations of these. Papers provide excellent electrical properties, good dimensional stability, moderate strength, and uniform appearance.

Cotton cloth is used for applications requiring good mechanical strength. The lighter-weight fabrics are not as strong but have excellent machinability.

Asbestos, in the form of paper, mat, or woven fabric, provides excellent resistance to heat, flame, chemicals, and wear.

Glass-fiber reinforcements, in woven fabric or mat, form the strongest laminates. These laminates also have low moisture absorption and excellent heat resistance and electrical properties.

Property sketch of representative plastic laminates

NEMA Grade →	X	XXX	XXP	XXXP	XXXP
Base material →	Paper	Paper	Paper	Paper	Paper
Property / Resin →	Phenolic	Phenolic	Phenolic	Phenolic	Phenoli
PHYSICAL					
Specific gravity	1.36	1.32	1.32	1.30	1.30
Specific volume (in.^{3}/lb)	20.4	21.0	21.0	21.3	21.3
Water absorption, 24 h (%)					
1/16 in.	6.00	1.40	1.80	1.00	0.75
1/8 in.	3.30	0.95	1.10	0.75	0.55
1/2 in.	1.10	0.45	—	—	—
MECHANICAL					
Tensile strength psi					
Lengthwise	20,000	15,000	11,000	12,400	12,400
Crosswise	16,000	12,000	8,500	9,500	7,000
Compressive strength (psi)					
Flatwise	36,000	32,000	25,000	25,000	25,000
Edgewise	19,000	25,000	—	—	—
Shear strength (psi)	12,000	10,000	11,000	11,000	11,000
Impact strength, Izod, min (ft-lb/in. of notch)					
Flatwise	0.55	0.40	—	—	—
Edgewise	0.50	0.35	—	—	—
Flexural strength (psi)					
Min for 1/8-in. specimen					
Lengthwise	25,000	13,500	14,000	12,000	12,000
Crosswise	22,000	11,800	12,000	10,500	10,500
Flexural modulus (10^5 psi)					
Lengthwise	18	13	9	10	10
Crosswise	13	10	7	7	7
Hardness, Rockwell M	110	110	100	105	95
Bonding strength, min (lb)	700	950	—	—	—
THERMAL					
Thermal conductivty (10^{-5} cal-cm/sec-cm^2-°C)	7.0	7.0	7.0	7.0	7.0
Coef of thermal expansion (10^{-5} in./in.-°C)	2	2	2	2	2
Continuous no-load service temp (°F)	225	250	250	250	250
Flammability rating, UL 94	HB	HB	HB	HB	HB
ELECTRICAL					
Dissipation factor, max					
At 1 MHz, Condition A	0.06	0.038	0.040	0.035	0.035
Dielectric constant, max					
At 1 MHz, Condition A	6.0	5.3	5.0	4.6	4.6
Dielectric breakdown (kV)					
Parallel to laminations 1/16 in., step by step, Condition A	—	50	60	60	60
Insulation resistance (megohms)					
96 h, 35°C, 90% RH	—	1,000	500	20,000	50,000

Nylon fabrics provide excellent electrical and mechanical properties and chemical resistance, but laminates reinforced with these materials lack dimensional stability at elevated temperatures.

Metal matrix composites

Metal matrix composites (MMCs) have mechanical properties that are superior to those of monolithic metals, and frequently to those of polymer matrix composites, especially at high temperature. The ability to tailor both mechanical and physical characteristics of MMCs is a unique and important feature of these materials.

A significant and increasing number of materials exist, with a wide variety of attractive properties. Although the technology is relatively young, there

CE otton fabric Phenolic	**LE** Fine-weave cotton fabric Phenolic	**AA** Asbestos fabric Phenolic	**G-3** Cont filament glass fabric Phenolic	**G-7** Cont filament glass fabric Silicone	**G-9** Cont filament glass fabric Melamine	**G-10** Cont filament glass fabric Epoxy
1.33	1.33	1.70	1.65	1.68	1.90	1.82
20.8	20.8	16.3	16.8	16.5	14.6	15.4
2.20	1.95	3.00	2.70	0.55	0.80	0.25
1.60	1.30	2.50	2.00	0.35	0.70	0.15
0.75	0.70	1.25	1.50	0.20	0.40	0.10
9,000	12,000	12,000	23,000	23,000	50,000	45,000
7,000	8,500	10,000	20,000	18,500	40,000	40,000
39,000	37,000	38,000	50,000	45,000	70,00	60,000
24,500	25,000	21,000	17,500	14,000	25,000	35,000
11,000	11,500	12,000	18,000	17,000	20,000	19,000
1.6	1.3	3.6	6.5	6.5	12.0	7.0
1.4	1.0	3.0	5.5	5.5	8.0	5.5
17,000	15,000	18,000	40,000	20,000	55,000	55,000
14,000	13,500	16,000	30,000	18,000	35,000	45,000
9	9	16	15	14	25	27
8	8	14	12	12	20	22
105	105	103	100	100	120	111
1,800	1,600	1,800	850	650	1,700	2,000
7.0	7.0	—	—	7.0	7.0	—
2	2	1.5	1.8	—	1.0	—
250	250	275	290	460	325	250
HB	HB	HB	HB	V-0	V-0	HB
0.055	0.055	—	0.003	0.003	0.017	0.025
5.8	5.8	—	5.5	4.2	7.2	5.2
35	40	—	—	32	60	45
—	—	—	—	2,500	10,000	200,000

are a number of significant production applications, notably the space shuttle fuselage struts, space telescope boom-waveguide, and diesel engine pistons. Numerous other items are under development. In coming years, metal-matrix composites are expected to be an important class of materials in the aerospace and commercial industries.

Properties and applications: MMCs are materials consisting of metal alloys reinforced with fibers, whiskers, particulates, and wires. Because of their superior mechanical properties and unique physical characteristics, such as low coefficients of thermal expansion, they are attractive for many structural and nonstructural applications. The most notable production applications to date are the space shuttle struts, NASA space telescope boom/ waveguides, and Toyota and Mitsubishi diesel engine pistons.

The space shuttle uses about 240 struts made from aluminum reinforced with boron fibers. The NASA space telescope has two rectangular antenna support booms that also serve as waveguides. They are fabricated from aluminum reinforced with graphite fibers. Toyota has announced that it currently is mass producing aluminum diesel-engine pistons which are locally reinforced with ceramic fibers, eliminating the need for nickel/cast iron inserts. The current annual production rate is estimated to be 350,000. Mitsubishi is using diesel-engine pistons of aluminum reinforced with silicon carbide whiskers.

Use of MMCs in automotive pistons is a particularly significant development. It suggests that these materials can be reliably fabricated on a large scale, can function in a severe environment, and be competitive in a cost-sensitive application. Many other automotive piston suppliers have active metal-matrix composite programs, and additional production applications are anticipated. Other engine components, such as connecting rods, are under development.

Numerous programs are under way to apply MMCs to Army, Navy, and Air Force structural components. The unique physical characteristics of MMCs are just beginning to be exploited. As an example, Hitachi has developed an experimental low-thermal-expansion heat sink of copper reinforced with graphite fibers.

Although many MMCs with widely different properties exist, some general advantages of these materials over monolithic (unreinforced) metals and polymer matrix composites can be cited. Compared to monolithic metals, MMCs have:

- Higher strength-to-density ratios
- Higher stiffness-to-density ratios
- Better fatigue resistance
- Better elevated temperature properties
  - — Higher strength
  - — Lower creep rate
- Lower coefficients of thermal expansion
- Better wear resistance

The advantages of MMCs over polymer matrix composites are:

- Higher temperature capability
- Fire resistance
- Higher transverse stiffness and strength
- No moisture absorption
- Higher electrical and thermal conductivities
- Better radiation resistance
- No outgassing

- Fabricability of whisker and particulate-reinforced MMCs with conventional metalworking equipment.

Some of the disadvantages of MMCs compared to monolithic metals and polymer matrix composites are:

- Higher cost of some material systems
- Relatively immature technology
- Complex fabrication methods for fiber-reinforced systems (except for casting)
- Limited service experience

Numerous combinations of matrices and reinforcements have been tried since work on MMC began in the late 1950s. However, MMC technology is still in the early stages of development, and other important systems undoubtedly will emerge.

Reinforcements: MMC reinforcements can be divided into five major categories: continuous fibers, discontinuous fibers, whiskers, particulates, and wires. With the exception of wires, which are metals, reinforcements generally are ceramics.

Key continuous fibers include boron, graphite (carbon), alumina, and silicon carbide. Table 1 presents representative properties of these materials. Boron fibers are made by chemical vapor deposition (CVD) of this material on a tungsten core. Carbon cores have also been used. These relatively thick monofilaments are available in 4.0, 5.6, and 8.0-mil diameters. To retard reactions that can take place between boron and metals at high temperature, fiber coatings of materials such as silicon carbide or boron carbide are sometimes used.

Silicon carbide monofilaments are also made by a CVD process, using a tungsten or carbon core. A Japanese multifilament yarn, designated as silicon carbide by its manufacturer, is also commercially available. This material, however, made by pyrolysis of organometallic precursor fibers, is far from pure silicon carbide and its properties differ significantly from those of monofilament silicon carbide.

Continuous alumina fibers are available from several suppliers. Chemical compositions and properties of the various fibers are significantly different. Graphite fibers are made from two precursor materials, polyacrilonitrile (PAN) and petroleum pitch. Efforts to make graphite fibers from coal-based pitch are under way. Graphite fibers with a wide range of strengths and moduli are available.

The leading discontinuous fiber reinforcements at this time are alumina and alumina-silica. Both originally were developed as insulating materials. The major whisker material is silicon carbide. The leading U.S. commercial product is made by pyrolysis of rice hulls. Silicon carbide and boron carbide, the key particulate reinforcements, are obtained from the commercial abrasives industry. Silicon carbide particulates are also produced as a byproduct of the process used to make whiskers of this material.

A number of metal wires including tungsten, beryllium, titanium, and molybdenum have been used to reinforce metal matrices. Currently, the most important wire reinforcements are tungsten wire in superalloys and superconducting materials incorporating niobium-titanium and niobium-tin in a copper matrix. The reinforcements cited above are the most important at this time. Many others have been tried over the last few decades, and still others undoubtedly will be developed in the future.

Matrix materials and key composites: Numerous metals have been used as matrices. The most important have been aluminum, titanium, magnesium, and copper alloys and superalloys.

The most important MMC systems are:

- Aluminum matrix
  - — Continuous fibers: boron, silicon carbide, alumina, graphite
  - — Discontinuous fibers: alumina, alumina-silica
  - — Whiskers: silicon carbide
  - — Particulates: silicon carbide, boron carbide
- Magnesium matrix
  - — Continuous fibers: graphite, alumina
  - — Whiskers: silicon carbide
  - — Particulates: silicon carbide, boron carbide
- Titanium matrix
  - — Continuous fibers: silicon carbide, coated boron
  - — Particulates: titanium carbide
- Copper matrix
  - — Continuous fibers: graphite, silicon carbide
  - — Wires: niobium-titanium, niobium-tin
  - — Particulates: silicon carbide, boron carbide, titanium carbide.
- Superalloy matrices
  - — Wires: tungsten

Characteristics and design considerations: The superior mechanical properties of MMCs is the major driving force for their use. An important characteristic of MMCs, however, and one they share with other composites, is that by appropriate selection of matrix materials, reinforcements, and layer orientations, it is possible to tailor the properties of a component to meet the needs of a specific design.

For example, within broad limits, it is possible to specify strength and stiffness in one direction, coefficient of expansion in another, and so forth. This is rarely possible with monolithic materials.

Monolithic metals tend to be isotropic, that is, to have the same properties in all directions. Some processes such as rolling, however, can impart anisotropy, so that properties vary with direction. The stress-strain behavior of monolithic metals is typically elastic-plastic. Most structural metals have considerable ductility and fracture toughness.

The most important structural polymer matrix composites (PMCs) are reinforced with straight, parallel, continuous fibers or with fabrics. The key PMC reinforcing fibers are E-glass, S-2 glass, graphite carbon, and aramid (Kevlar 49). Epoxies are presently the most important aerospace resin systems, but there is considerable interest in polymers with higher temperature capability, such as polyimides and bismaleimides.

Polymer matrix composites are highly anisotropic. They are strong and stiff parallel to the fiber direction, but their stiffness and strength are low perpendicular to it. PMCs do not yield elastically, and their stress-strain curves are generally linear to failure. An exception is when transverse cracking in some plies causes a "knee" in the curve, with a reduction in secondary modulus.

The wide variety of MMCs have properties that differ dramatically. Factors influencing their characteristics include:

- Reinforcement properties, form, and geometric arrangement
- Reinforcement volume fraction
- Matrix properties, including effects of porosity
- Reinforcement-matrix interface properties
- Residual stresses arising from the thermal and mechanical history of the composite
- Possible degradation of the reinforcement resulting from chemical reactions at high temperatures, and mechanical damage from processing, impact, etc.

Particulate-reinforced MMCs, like monolithic metals, tend to be isotropic. The presence of brittle reinforcements and perhaps of metal oxides, however, tends to reduce their ductility and fracture toughness. Continuing development may reduce some of these deficiencies.

The properties of materials reinforced with whiskers depend strongly on their orientation. Randomly oriented whiskers produce an isotropic material. Processes such as extrusion can orient whiskers, however, resulting in anisotropic properties. Whiskers also reduce ductility and fracture toughness.

MMCs reinforced with aligned fibers have anisotropic properties. They are stronger and stiffer in the direction of the fibers than perpendicular to them. The transverse strength and stiffness of unidirectional MMCs (materials having all fibers oriented parallel to one axis), however, are frequently great enough for use in components such as stiffeners and struts. This is one of the major advantages of MMCs over PMCs, which can rarely be used without transverse reinforcement.

Because the modulus and strength of metal matrices are significant with respect to those of most reinforcing fibers, their contribution to composite behavior is important. The stress-strain curves of MMCs often show significant nonlinearity resulting from yielding of the matrix.

Another factor that has a significant effect on the behavior of fiber-reinforced metals is the frequently large difference in coefficient of expansion between the two constituents. This can cause large residual stresses in composites when they are subjected to significant temperature changes. In fact, during cool down from processing temperatures, matrix thermal stresses are often severe enough to cause yielding. Large residual stresses can also be produced by mechanical loading.

Although fibrous MMCs may have stress-strain curves displaying some nonlinearity, they are essentially brittle materials, as are PMCs. In the absence of ductility to reduce stress concentrations, joint design becomes a critical design consideration. Numerous methods of joining MMCs have been developed, including metallurgical and polymeric bonding and mechanical fasteners.

Fabrication methods: Fabrication methods are an important part of the design process for all structural materials, including MMCs. Considerable work is under way in this critical area. Significant improvements in existing processes and development of new ones appear likely.

Current methods can be divided into two major categories, primary and secondary. Primary fabrication methods are used to create the MMC from its constituents. The resulting material may be in a form that is close to the desired final configuration, or it may require considerable additional processing, called secondary fabrication, such as forming, rolling, metallurgical bonding, and machining. The processes used depend on the type of reinforcement and matrix.

A critical consideration is reactions that can occur between reinforcements and matrices during primary and secondary processing at the high temperatures required to melt and form metals. These impose limitations on the kinds of constituents that can be combined by the various processes. Sometimes, barrier coatings can be successfully applied to reinforcements, allowing them to be combined with matrices that otherwise would be too reactive. For example, the application of a coating such as boron carbide permits the use of boron fibers to reinforce titanium. Potential reactions between matrices and reinforcements, even coated ones, is also an important criterion in evaluating the temperatures and corresponding lengths of time to which MMCs may be subjected in service.

Relatively large-diameter monofilament fibers, such as boron and silicon carbide, have been incorporated into metal matrices by hot pressing a layer of parallel fibers between foils to create a monolayer tape. In this operation, the metal flows around the fibers and diffusion bonding occurs. The same procedure can be used to produce diffusion-bonded laminates with layers of fibers oriented in specified directions to meet stiffness and strength requirements for a particular design. In some instances, laminates are produced by hot pressing monolayer tapes in what can be considered a secondary operation.

Monolayer tapes are also produced by spraying metal plasmas on collimated fibers, followed by hot pressing. Structural shapes can be fabricated by creep and superplastic forming of laminates in a die. An alternate process is to place fibers and unbonded foils in a die and hot press the assembly.

The boron/aluminum struts used on the space shuttle are fabricated from monolayer foils wrapped around a mandrel and hot isostatically pressed to diffusion bond the foil layers together and, at the same time, to diffusion bond the composite laminate to titanium end fittings.

Composites can be made by infiltrating liquid metal into a fabric or prearranged fibrous configuration called a preform. Frequently, ceramic or organic binder materials are used to hold the fibers in position. The latter is burned off before or during infiltration. Infiltration can be carried out under vacuum, pressure, or both. Pressure infiltration, which promotes wetting of the fibers by the matrix and reduces porosity, is often called squeeze casting.

Casting methods appear to have great promise for low-cost fabrication. Toyota is believed to produce its fiber-reinforced aluminum diesel engine pistons using a preformed fiber ring in a squeeze-casting process. Mitsubishi apparently uses a similar approach with silicon-carbide whiskers for its pistons.

At the current time, the most common method used to make graphite/aluminum and graphite/magnesium composites is by infiltration. Graphite yarn is first passed through a furnace to burn off any sizing that may have been applied. Next it goes through a CVD process that applies a coating of titanium and boron which promotes wetting by the matrix. Then it immediately passes through a bath or fountain of molten metal, producing an infiltrated bundle of fibers known as a "wire." Plates and other structural shapes are produced in a secondary operation by placing the wires between foils and pressing them, as is done with monofilaments. Recent development of "air stable" coatings permits use of other infiltration processes, such as casting, eliminating the need for "wires" as an intermediate step. Other approaches are under development.

A particularly important secondary fabrication method for titanium matrix composites is superplastic forming/diffusion bonding (SPF/DB). To reduce fabrication costs, continuous processes such as pultrusion and hot roll bonding are being developed.

Three basic methods are being used to make whisker and particulate-reinforced MMCs. Two use powdered metals; the other uses a liquid-metal approach, details of which are proprietary.

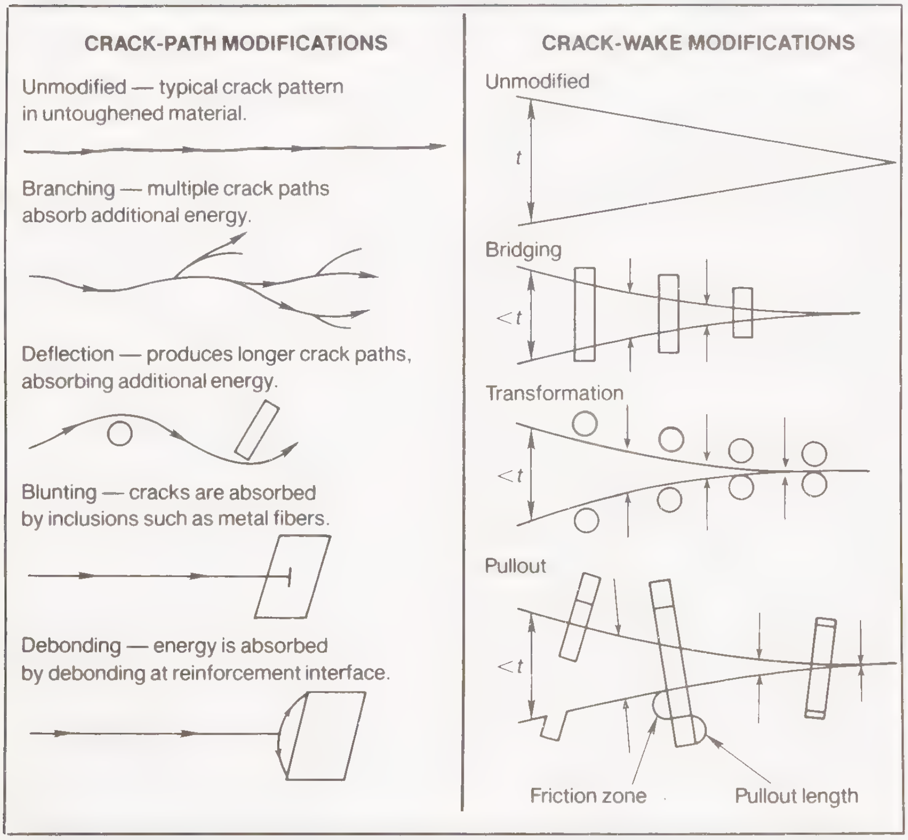
The two powder-metal processes differ primarily in the way the constituents are mixed. One uses a ball mill, the other employs a liquid to aid mixing, which is subsequently removed. Mixtures are then hot pressed into billets.

Secondary processes are similar to those for monolithic metals, including rolling, extrusion, spinning, forging, creep-forming, and machining. The latter poses some difficulties because the reinforcements are very hard.

TOUGHENING MECHANISMS

Two categories of toughening mechanisms affect ceramic matrix composites. One involves methods that make the crack follow a more tortuous path through the material. The other approach uses techniques that interact with the crack wake, making crack opening and growth more difficult. In both methods, crack growth is retarded or stopped because additional energy is absorbed as the crack propagates through the material.

An additional mechanism in fiber-reinforced materials is the load-carrying capability of the fibers after complete matrix failure. The mechanisms believed to be most influential in improving properties of ceramic-matrix composites are crack-wake bridging, reinforcement pullout, and fiber load carrying.


CRACK-PATH MODIFICATIONS
Unmodified — typical crack pattern in untoughened material.
Branching — multiple crack paths absorb additional energy.
Deflection — produces longer crack paths, absorbing additional energy.
Blunting — cracks are absorbed by inclusions such as metal fibers.
Debonding — energy is absorbed by debonding at reinforcement interface.
CRACK-WAKE MODIFICATIONS
Unmodified
t
Bridging
<t
Transformation
<t
Pullout
<t
Friction zone
Pullout length

Ceramic matrix composites

The class of materials known as ceramic matrix composites, or CMCs, shows considerable promise for providing fracture-toughness values similar to those for metals such as cast iron. Two kinds of damage-tolerant ceramic-ceramic composites are being developed. One incorporates a continuous reinforcing phase, such as a fiber; the other, a discontinuous reinforcement, such as whiskers. The major difference between the two is in their failure behavior. Continuous-fiber-reinforced materials do not fail catastrophically. After matrix failure, the fiber can still support a load. A fibrous failure is similar to that which occurs in wood.

Incorporating whiskers into a ceramic matrix improves resistance to crack growth, making the composite less sensitive to flaws. These materials are commonly described as being flaw tolerant. However, once a crack begins to propagate, failure is catastrophic.

Of particular importance to the technology of toughened ceramics has been the development of high-temperature silicon carbide reinforcements. Although other reinforcement materials are available, such as glass and carbon fiber, metal whiskers, and alumina-based products, this discussion focuses on SiC-based products because they are more applicable to high-temperature use.

SiC fibers, which are capable of withstanding temperatures to about 1,200°C, are manufactured from a polymer precursor. The polymer is spun into a fine thread, then pyrolized to form a 15-μm ceramic fiber consisting of fine SiC crystallites and an amorphous phase. An advantage of the process is that it uses technology developed for commercial fiber products such as nylon and polyester. Two commercial SiC fiber products are Ube Industries' Tyranno fiber and Nippon Carbon's Nicalon fiber, both from Japan.

SiC filaments are prepared by chemical vapor deposition. A thick layer of silicon carbide is deposited on a thin fiber substrate of tungsten or carbon. Diameter of the final product is about 140 μm.

Although developed initially to reinforce aluminum and titanium matrices, SiC filaments have since been used as reinforcement in silicon nitride. The material is manufactured by Avco Specialty Materials/Textron in the U.S. and by Sigma Composite Materials in the Federal Republic of Germany.

SiC whiskers consist of a fine (0.5-μm-diameter) single-crystal structure in lengths to 100 μm. The material is strong (to 15.9 GPa) and is stable at temperatures to 1,800°C. Whiskers can be produced by heating SiO_2 and carbon sources with a metal catalyst in the proper environments. These reinforcements are manufactured on a commercial scale in Japan by Tateho Chemical Industries and Tokai Carbon Co.

Although these materials are relatively new, at least one successful commercial product is already being marketed. An SiC-whisker-reinforced alumina cutting-tool material is being used to machine nickel-based superalloys. In addition, considerable interest has been generated in reinforcing other matrices such as mullite, silicon carbide, and silicon nitride for possible applications in automotive and aerospace industries.

Interface conditions: In addition to developments in reinforcement materials, advances in controlling the interfacial bond between matrix and reinforcement have led to further mechanical property improvements of ceramic-ceramic composites. The interfacial bond must be optimized to promote favorable toughening mechanisms such as crack deflection and crack bridging. Without proper interface control, a brittle polyphase material results, rather than a toughened composite.

Toughness improvements by interfacial modifications have been made in both fiber and whisker-reinforced systems. Interface control has resulted in the development of toughened fiber-reinforced glass-ceramic matrix materials at the United Technologies Research Center and of toughened fiber-reinforced zirconia-based materials at the Naval Research Laboratories. At present, interfacial control is more advanced for fiber-reinforced composites than for whisker-reinforced materials.

One current approach is to design the interface so it has a parting layer that promotes crack deflection parallel to the fiber length. The parting layer protects the fiber from damage by deflecting cracks, enabling the undamaged reinforcement to support load and bridge cracks during matrix failure. Thus, the composite does not fail catastrophically. Fracture morphology is comparable to that of the fibrous fracture of wood structures. Current materials being used for such interfaces are boron nitride and carbon, materials that have weak crystallographic orientations that preferentially delaminate.

Modifications to the interfacial zone of whisker-reinforced composites are in their developmental infancy because of the difficulty of applying thin coatings on fine whiskers. Studies at Oak Ridge National Laboratories have demonstrated that thermal treatments of whiskers prior to their incorporation into an alumina matrix can increase fracture toughness of the composite. In those materials, best toughness — about 8.0 $\mathrm{MPa}\sqrt{\mathrm{m}}$ — results with whisker surfaces modified to be carbon rich and oxygen poor.

Current mechanistic studies at the University of California/Santa Barbara are directed toward understanding the role of interfacial structure on toughness of ceramic-matrix composites. In addition, some investigators feel that the approaches used by the carbon-carbon community, such as applying various CVD coatings to seal off the fibers, may result in near-term solutions for improving toughness of fiber-reinforced ceramics.

In whisker-reinforced materials, the matrix usually seals off the interface region from the composite exterior. This protects the interface from oxidizing environments. However, once cracks are initiated, they allow access of atmospheric elements into the interior. As with fiber-reinforced materials, new interface compositions must be developed that are stable in oxidizing environments.

In addition, there is still a need to develop further understanding of the role of whisker interfaces on toughening mechanisms for ceramics. The requirements of fiber and whisker-reinforced systems appear to have many similarities.

Reinforcement needs: Although the current interest in ceramic-matrix composites has resulted from improved reinforcements, there is still a need for further developments. Specifically, reinforcements are needed for ceramic matrices for service at temperatures greater than 1,800°C.

Currently available polymer-derived fibers are limited because they deteriorate above 1,200°C. A program aimed at developing higher temperature fiber has been sponsored by the Dept. of Defense, combining the expertise of Dow Corning in silicon-based materials with that of Celanese in fiber technology. From this program has come a new fiber material that has higher thermal stability than commercially available fibers.

SiC filament material has limitations in oxidizing environments due to its carbon core and carbon surface coatings that oxidize above 600°C. These filaments are designed for use in aluminum and titanium matrices. A similar product, engineered for ceramic matrices, is needed.

SiC whiskers are a nearer-term reinforcement for commercial ceramic-matrix composites, having already demonstrated success in reinforcing alumina. As with the other reinforcing materials, the whiskers currently being produced are more appropriate for reinforcing metals. Current theory indicates that thicker whiskers (1 to 3 μm) are more appropriate for ceramics. Such materials are now under development.

Dimox process: Ceramic matrix composites are steadily moving from the laboratory to initial commercial applications. For example, engineers are currently evaluating these materials for use in the hot gas zones of gas turbine engines, because ceramics are known for their strength and favorable creep behavior at high temperatures. Advanced ceramics, for example, can potentially be used at temperatures 400 to 900°F above the maximum operating temperature for superalloys.

Until recently, however, there has been more evaluation than implementation of advanced ceramics for various reasons. Monolithic or single-component ceramics, for example, lack the required damage tolerance and toughness. Engine designers are put off by ceramic material's potential for catastrophic, brittle failures. While many CMCs have greater toughness, they are also difficult to process by traditional methods, and may not have the needed long-term high-temperature resistance.

A relatively new method for producing CMCs developed by Lanxide Corp., Newark, DE, promises to overcome the limitations of other ceramic technologies. Called the Dimox directed metal oxidation process, it is based on the reaction of a molten metal with an oxidant, usually a gas, to form the ceramic matrix. Unlike the sintering process, in which ceramic powders and fillers are consolidated under heat, directed metal oxidation grows the ceramic matrix material around the reinforcements.

Examples of ceramic matrices that can be produced by the Dimox directed metal oxidation process include Al_2O_3, Al_2TiO_5, AlN, TiN, ZrN, TiC, and ZrC. Filler materials can be anything chemically compatible with the ceramic, parent metal, and growth atmosphere.

The first step in the process involves making a shaped preform of the filler material. Preforms consisting of particles are fabricated with traditional ceramic forming techniques, while fiber preforms are made by weaving, braiding, or laying up woven cloth. Next, the preform is put in contact with the parent metal alloy. A gas-permeable growth barrier is applied to the surfaces of this assembly to limit its shape and size.

The assembly, supported in a suitable refractory container, is then heated in a furnace. For aluminum systems, temperatures typically range from 1,650 to 2,100°F. The parent metal reacts with the surrounding gas atmosphere to grow the ceramic reaction product through and around the filler to form a CMC.

Capillary action within the growing ceramic matrix continues to supply molten alloy to the growth front. There, the reaction continues until the growing matrix reaches the barrier. At this point, growth stops, and the part is cooled to ambient temperature. To recover the part, the growth barrier and any residual parent metal are removed. However, some of the parent metal (5 to 15% by volume) remains within the final composite in micron-sized interconnected channels.

Traditional ceramic processes use sintering or hot pressing to make a solid CMC out of ceramic powders and filler. Part size and shapes are limited by equipment size and the shrinkage that occurs during densification of the powders can make sintering unfeasible. Larger parts pose the biggest shrinkage problem. Advantages of the directed metal oxidation process include no shrinkage since matrix formation occurs by a growth process. As a result, tolerance control and large part fabrication can be easier with directed metal oxidation.

In addition, the growth process forms a matrix whose grain boundaries are free of impurities or sintering aids. Traditional methods often incorporate these additives, which reduce high-temperature properties. And cost comparisons show the newer process is a promising replacement for traditional methods.

Fibers

The fiber industry is divided between natural fibers — those from plant, animal, or mineral sources — and synthetic fibers. Many synthetic fibers have been developed specifically to replace natural fibers because synthetics usually behave more predictably and are more uniform in size. Often, synthetic fibers are less costly than their natural counterparts. In the garment industry, for example, the acrylic and rayon fibers were developed to replace more costly natural wool and silk.

For engineering purposes, metal, ceramic, glass, and organically derived synthetic fibers are more significant. Nylon, for example, is used for belting, nets, hose, rope, parachutes, webbing, ballistic cloths, and as reinforcements in tires.

Metal and ceramic fibers are used in high-strength, high-temperature, lightweight composite materials for aerospace applications. Fibers improve the strength-to-weight ratio of base materials such as titanium and aluminum. Anisotrophic properties can be designed into a part made from a fiber composite by selectively aligning the fiber/base layup.

Fibers of stainless steel or aluminum provide conductivity in plastic components for static-electricity dissipation or, with higher loadings, shielding from electromagnetic interference (EMI). Shielding is particularly important for housings of computers, copiers, and other business machines. Because only small levels of stainless-steel fibers are needed, base-resin properties remain relatively unchanged, and the composite has good colorability.

Among the strongest materials are metal fibers formed by controlled solidification and cold drawing. Some nonmetallic fibers such as aluminum oxide and silicon carbide are nearly as strong as metal fibers but have a higher modulus of elasticity. Fibers in a metal matrix combine the strength of the fiber with ductility or other characteristics of the matrix. Many combinations of properties are possible — for example, tungsten fibers in a copper matrix add the strength of the fiber to the conductivity of the matrix. Aluminum oxide and silicon carbide are among several fibers added to aluminum to produce high strength-to-weight ratio composites.

One application using an alumina/silica ceramic-fiber reinforcement in an aluminum matrix is that of diesel pistons. The reinforcement, placed either in the combustion-bowl or ring-groove area, is a preform of Fiberfrax (from Carborundum Co.) ceramic fiber. The pistons are produced by the squeeze-cast process.

Glass fibers, the most widely used reinforcement for plastic and rubber products, are also the finest (smallest diameter) of all fibers, typically 1 to 4 microns in diameter. Because glass fibers have a large surface area in proportion to volume (a ¾-in.-diameter bead of glass is stretched into over 97 miles of fiber) surface conditions of the fiber have a strong influence on its strength and behavior.

Glass fibers improve both short-term and long-term mechanical properties of a resin. The fibers also improve creep resistance, thermal conductivity, and heat-deflection temperature as well as the tribological properties of the base resin. The degree of improvement depends on the efficiency of the sizing system that bonds the resin to the fibers. Glass beads and unsized milled-glass fibers, on the other hand, increase the wear factor of the mating surface and the coefficient of friction.

Glass fibers are frequently used in combination with silicone and PTFE lubricants which offset the negative wear effects that the glass fibers have on surface characteristics. The use of silicone only, in conjunction with glass fibers, is not recommended, however. PTFE provides far more protection to the mating surface and should be used (with or without silicone) if the wear rate of the mating surface is important.

Most glass-reinforced products are made with E-glass (electrical glass), which has good electrical and mechanical properties and high heat resistance. E-glass is available as chopped fiber, milled fiber, continuous roving, woven roving, woven fabric, and reinforcing mat. Tensile strength is 500,000 psi modulus is 10.5 million, and elongation can be as high as 4.8%.

Applications are in many industries, ranging from tub/shower units and boat hulls to tanks, ducts, and automotive exterior panels. Fabrication of components, using both thermoplastic and thermoset matrix resins is done by all conventional molding processes.

For higher performance than provided by E-glass, S-glass offers 30% higher tensile strength and 18% higher modulus. S-glass is used in such applications as aircraft flooring, helicopter

DEFINING FIBER TERMS

Terms commonly used by the fiber industry:

Fiber is a single, continuous material whose length is at least 200 times its width or diameter.

Filament is an "endless" or continuous fiber.

Staple is a measurable, relatively short fiber. All natural fibers are staple fibers. Man-made filament fibers are often cut into short, staple lengths.

Yarn is a continuous strand or bundle of fibers.

Fabrics are sheets of fibers or yarns woven, knitted, or otherwise physically bonded together.

Felts are nonwoven "entanglements" of fibers or yarns.

Denier, abbreviated den., is the weight, in grams, of 9,000 meters of fiber. This unit of measurement reflects both fiber size and density. For man-made fibers, one-den. Fiber is considered "very fine"; 20 to 900-den. fibers are common apparel grades, while fibers in the 1,100 to 4,400-den. range are usually the high-strength, carpet and engineering grades. Yarn specifications usually include the number of fibers in the strand. A 50/20 yarn, for example, is a 50-den. yarn made from 20 fibers.

Tenacity is a measure of fiber strength. Expressed in gm/den., tenacity is also called "breaking strength."

blades, and filament-wound pressure containers.

Carbon fibers offer the widest range of stiffness of any material — from about 5 million to as high as 100-million psi. Most commonly used of these materials, however, are those fibers in the midrange, having moduli in the 30 to 40-million-psi range because they have the most useful balance of properties.

Used alone or as a part of a hybrid reinforcement with glass or aramid, carbon adds considerable strength and stiffness to engineering resins. In chopped form, molding procedures of carbon-reinforced composites are essentially the same as those used for glass-reinforced compounds. In tape form, often with an epoxy resin, the fibers are usually laid up as laminates, with the continuous fibers at various angles to one another.

In between chopped and continuous fibers are the recently introduced long-fiber-reinforced composites, which are available with either carbon or glass-fiber reinforcement. In these compounds (ICI Advanced Materials and Polymer Composites Inc.) the carbon fibers averaging about 0.5 in. long (same length as the pellets) provide strength values between those of the chopped and continuous-fiber-reinforced composites.

Because of their light weight and high strength and stiffness, carbon-reinforced composites are used in aircraft components. Their high-temperature properties qualify them for applications such as pump packings, bearings, and brake components. Sports equipment of "graphite" materials include skis, racquets, golf club shafts, and lightweight bicycle parts.

Carbon fibers added to thermoplastic resins provide the highest strength, modulus, heat-deflection temperature, creep, and fatigue-endurance values commercially available in composites. These property improvements, coupled with greatly increased thermal conductivity and low friction coefficients, make carbon fibers ideal for wear and frictional applications where the higher cost can be tolerated. In applications where the abrasive nature of glass fibers wears the mating surface, the softer carbon fibers can be substituted to reduce the wear rate. Carbon fibers can also be used in conjunction with internal lubricants to further improve surface characteristics of most thermoplastic resin system.

Another useful property of carbon-fiber-reinforced thermoplastics is their low volume and surface resistivities. Most resin systems reinforced with 15% or more carbon fibers can effectively dissipate static charge, which is a problem common to gears, slides, and bearings used in business-machine, textile, electrical, and conveying equipment.

Aramid fibers (aromatic polyamides) are characterized by excellent environmental and thermal stability, static and dynamic fatigue resistance, and impact resistance. These fibers have the highest specific tensile strength (strength/density ratio) of any commercially available continuous-filament yarn. Aramid-reinforced thermoplastic composites have excellent wear resistance and near-isotropic properties — characteristics not available with glass or carbon-reinforced composites.

Aramid fiber, tradenamed Kevlar (Du Pont), is available in several grades and property levels for specific applications. The grade designated simply as Kevlar is made specifically to reinforce tires, hoses and belting, such as V-belts and conveyor belts.

Kevlar 29 is similar to the basic Kevlar in properties but is designated specifically for use in ropes and cables, protective apparel, and as the substrate for coated fabrics. In short fiber or pulp form, Kevlar 29 can substitute for asbestos in friction products or gaskets. Fabrics of Kevlar 29 can be made into bullet-resistant vests. Clothing made from Kevlar 29 can be as heat resistant as that made from asbestos and also be extremely cut resistant.

Kevlar 49 has half the elongation (2.5%) and twice the modulus (18×10^6 psi) of Kevlar 29. Applications are principally in reinforcing plastic compounds used in lightweight aircraft boat hulls and sports equipment. Composites containing Kevlar are also used as interior panels and secondary structural parts, such as fairings and doors on commercial aircraft.

Kevlar 149 is a highly crystalline aramid that has a modulus of elasticity 40% greater than that of Kevlar 49 and a specific modulus nearly equal to that of high-tenacity graphite fibers. It is used to reinforce composites for aircraft components.

Aramid fibers are stronger on a weight basis than steel or aluminum, but they are not as easy to work with as are glass and carbon. The high surface energy of the lightweight fibers makes wetting of the fibers and dispersion in resins difficult. Also, the fibers, having low compressive strength, are easily damaged in mixing and molding operations, which reduces composite properties. The first problem has been minimized somewhat with proprietary sizing/coupling systems, but fiber damage is still being worked on. Consequently, strength improvement in aramid-reinforced composites is not a reason to use these materials. But there are advantages offered by aramid/resin composites: Warpage and thermal expansion are low, abrasion resistance is high, and mechanical and thermal properties in molded parts are nearly uniform in all directions.

Thermoplastic fibers are also used to reinforce composite materials. Two such families are Compet and Spectra fibers, both products of Allied-Signal Corp. Thermoplastic fibers are particularly effective where high-shear processing would degrade conventional glass-fiber reinforcement, thereby reducing performance of the composite.

Compet fibers of nylon and polyester provide excellent impact resistance, surface appearance, and abrasion and corrosion resistance. They were developed to provide a degree of toughness and impact strength in brittle thermoset resins. Two polyester grades provide regular and reduced shrinkage characteristics, and a nylon grade is particularly resistant to alkalis. Tensile strength of the grades ranges from 120,000 to 150,000 psi. Compet fibers are often used in hybrid reinforcement systems, along with a stronger, higher modulus fiber.

Spectra, a lightweight, high-strength, extended-chain polyethylene fiber, is claimed to be ten times stronger than steel and 75% stronger than any other organic fiber available. Two grades of Spectra are available. One is a 1,200-denier fiber designed for high strength under intermittent loading conditions — sports equipment, ballistic fabrics, and medical products. The other is a 650-denier fiber for high strength under continuous load — sailcloth, high-tension ropes, and cables that must withstand flex-fatigue conditions. Tensile strength of Spectra fibers ranges from 370,000 to 430,000 psi. ■

Technical assistance for the **Composites** section was provided by: **Allied Signal Corp.**, New York, NY, Fibers; **Amoco Performance Products**, Chicago, IL, Thermoplastic composites, thermoset composites; **Brunswick Technetics**, DeLand, FL, Fibers; **Du Pont Co.**, Wilmington, DE, Thermoplastic composites, Fibers; **ICI Advanced Materials**, Exton, PA, Thermoplastic composites; **Lanxide Corp.**, Newark, DE, Ceramic matrix composites; **Metal Matrix Composites Information Analysis Center**, Santa Barbara, CA, Metal-matrix composites; **Synthane-Taylor Corp.**, Valley Forge, PA, Laminated plastics.

Elastomers and rubbers

Families and grades of both thermoset and thermoplastic rubber are now available to serve in almost any environment.

The rubber industry differentiates between the terms "elastomer" and "rubber" on the bases of how long a deformed material sample requires to return to its approximate original size after a deforming force is removed, and of its extent of recovery. ASTM D1566 defines an elastomer as "a macromolecular material which, at room temperature, is capable of recovering substantially in shape and size after removal of a deforming force."

The same standard is more specific and quantitative in defining rubber as "a material that is capable of recovering from large deformations quickly and forcibly . . . (and which), in its modified state, free of diluents, retracts within one minute to less than 1.5 times its original length after being stretched at room temperature to twice its length and held for one minute before release."

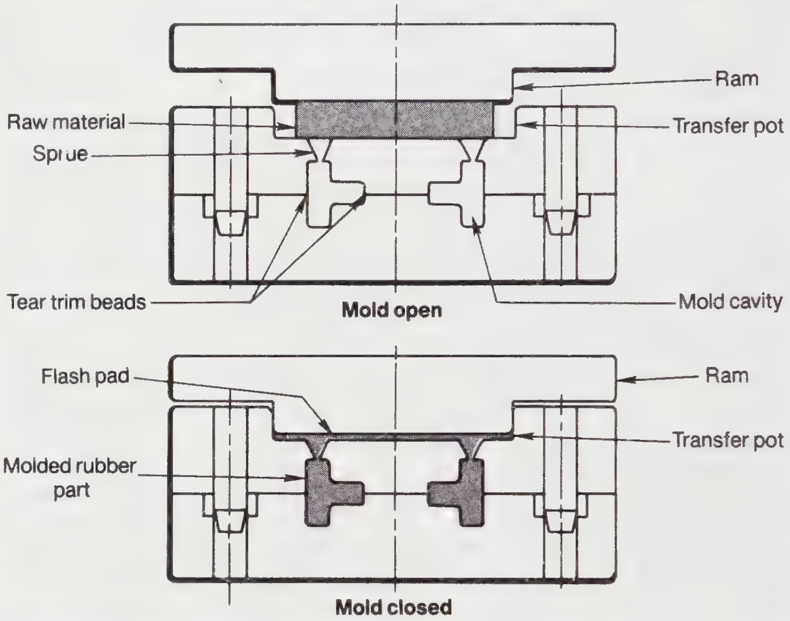
Thus, by these definitions, all rubbers are elastomers, but all elastomers are not rubbers, since no return time or deformation hold time is specified in the elastomer definition. Also, some plastics qualify as elastomers, according to the rather loose definition of that category.

Thermoset rubber

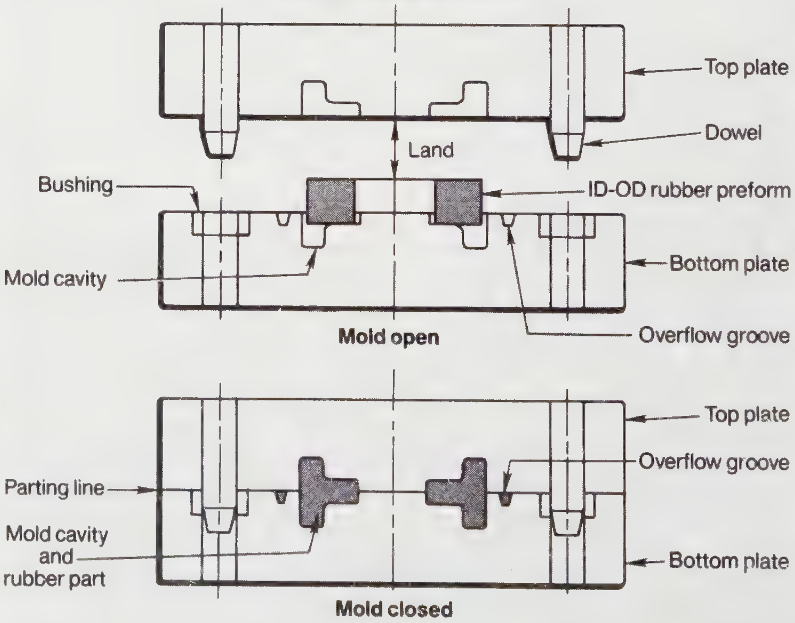
Originally, rubber meant the material obtained from the rubber tree *Hevea Brasiliensis*. Today, the term rubber means any materials capable of extreme deformability, with more or less complete recovery upon removal of the deforming force. Synthetic materials such as neoprene, nitrile, styrene butadiene (SBR), and butadiene rubber are now grouped with natural rubber. These materials serve engineering needs in fields dealing with shock absorption, noise and vibration control, sealing, corrosion protection, abrasion protection, friction production, electrical and thermal insulation, waterproofing, confining other materials, and load bearing.

Of all the available choices, SBR dominates the field, accounting for approximately one-half of all rubber — natural and synthetic — used in the

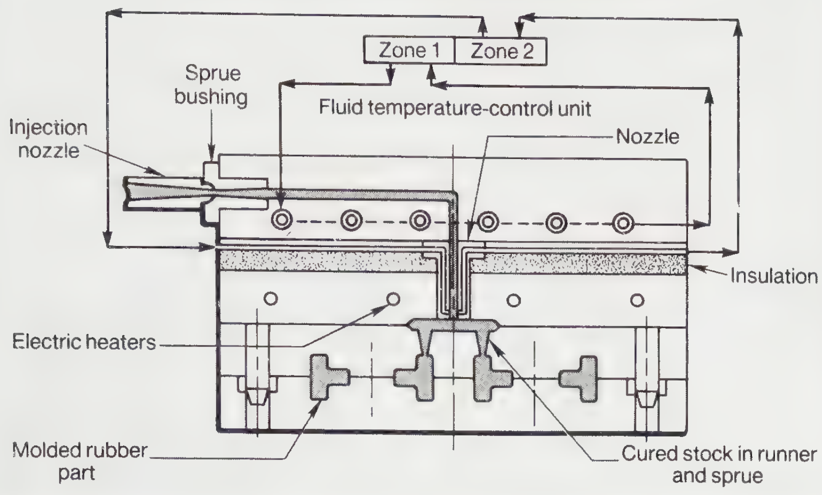
TRANSFER MOLDING



COMPRESSION MOLDING



COLD RUNNER SYSTEM FOR INJECTION MOLDING



U.S. The demand for SBR has been responsible for the building of a massive production capability for this material. More than half of SBR production goes into passenger-car tires in the U.S. Natural rubber is used almost exclusively in more demanding areas such as truck, bus, aircraft, and off-highway tires.

Nonoil-resistant rubbers

This group includes those materials in the Class A designation (no requirement regarding volume swell due to oil) and Types A and B designations (for continuous use not exceeding 70 and 100°C).

Natural rubber (NR, AA): The commercial base for natural rubber is latex, a milklike serum, generated by the tropical tree, Hevea Brasiliensis. The latex is collected in much the same fashion as maple sap. However, latex should not be confused with the sap of the tree. Latex is secreted in the inner bark of the tree, and a tree can be severely harmed if a tapping cut is deep enough to draw sap as well as latex. Naturally occurring latex is a dispersion of rubber in an aqueous serum containing various inorganic and organic substances. The rubber precipitated out of this solution can be characterized as a coherent elastic solid.

All other rubbers should be measured against natural rubber. For centuries it was the only rubber available, and it was used extensively, even before the discovery of vulcanization in 1839.

Synthetic rubbers have been developed either by accident or as the result of pressures of political upheaval or wartime restrictions and consequent unavailability of the natural product. However, no synthetic material has yet equaled the overall engineering characteristics and consequent wide latitude of application available with NR.

As with other rubbers, many grades and types of NR are available, produced by varying impurity levels, collection methods, and processing techniques. Natural rubber is generally considered to be the best of the general-purpose rubbers — those having properties and characteristics suitable for broad engineering applications. Compounds can be produced over a wider stiffness range with natural rubber than with any other material. Natural rubber is often the best choice for most applications except where an extreme performance or exposure requirement dictates the use of a special-purpose rubber, often at some sacrifice of other, less-critical characteristics.

Natural rubber has a large deformability capacity. This, coupled with its ability to strain crystallize, gives it added strength while deformed. Its high resilience, which is responsible for a very low heat buildup in flexing, makes NR a prime candidate for shock and severe dynamic loads. Thus, in applications where properties such as flexure, cut resistance, abrasion resistance, and general endurance would be adversely affected by heat in less-resilient rubbers, NR is recommended because of its low heat buildup.

NR also has low compression set and stress relaxation; these characteristics favor its application in sealing devices where maintenance of sealing forces and the surface conformability of high-quality soft stocks are important. Further advantages are excellent green (uncured) strength, building tack, and general processing characteristics.

Natural rubber does have some shortcomings. The useful service temperature of NR ranges generally from −65 to (in special cases) 250°F. Other drawbacks of NR such as poor oil, oxidation, and ozone resistance can be minimized, either by proper design accommodation and/or by compounding. Degradation from such environments are essentially surface effects that can be tolerated or minimized by using thicker cross sections, by shielding, or by adding antioxidants and antiozonants.

Natural rubber can often be the first choice for many high-performance applications if it can be made to survive in the service environment. It remains the best choice for tires, shock mounts and other energy absorbers, seals, isolators, couplings, bearings, springs, and dynamic applications.

Synthetic natural rubber (IR; AA): The synthetic rubber that is closest to duplicating the chemical composition of natural rubber is synthetic polyisoprene. It shares with natural rubber the properties of good uncured tack, high unreinforced strength, good abrasion resistance, and those characteristics that provide good performance in dynamic applications. However, because of some of the inherent impurities in the natural product that affect vulcanization characteristics in a positive fashion, natural rubber scores somewhat better on overall ratings.

A significant disadvantage of IR is its lack of green strength. IR can be used interchangeably for natural rubber in all but the most demanding applications. Specific product applications are about the same as those for natural rubber.

Styrene butadiene (SBR; AA, BA): This material emerged as a high-volume substitute for NR during World War II because of its suitability for use in tires. Despite the fact that the basic feedstock for SBR is crude oil, it has remained competitive in cost because of the extensive production capacity for SBR in the U.S.

SBR continues to be used in many applications where it replaced NR, even though it does not have the overall versatility of natural rubber and the other general-purpose materials. For most applications, SBR must be reinforced (hence, stock are stiffer) to have acceptable tensile strength, tear resistance, and general durability. SBR is significantly less resilient than NR, so it has higher heat buildup on flexing. Further, it does not have the processing and fabricating qualities of NR, lacking both green strength and building tack.

An important reason for the continued high volume use of SBR is that it did a creditable job in passenger car tires, having good abrasion resistance and general durability. Recently that picture has changed, however, because of the greater need for the green strength and building tack of natural rubber in radial tires and for the better low-temperature flexibility of natural rubber for snow tires. High-performance tires, such as for trucks and aircraft, have always been made from natural rubber if it was available.

Polybutadiene (BR; AA): This general-purpose, crude-oil-based rubber is even more resilient than natural rubber. It was the material that made the solid golf ball possible. It is also superior to natural rubber in low-temperature flexibility and in having less dynamic heat buildup. However, it lacks the toughness, durability, and cut-growth resistance of NR. It can be used as a blend in natural rubber or SBR to improve their low-temperature flexibility. Silicones have superior low-temperature flexibility, but this is achieved at a much higher price and at a sacrifice in other properties such as tensile strength, tear resistance, and general durability.

A large volume of polybutadiene is used in blends with other polymers to enhance their resilience and reduce heat buildup. It is also used in products requiring high resiliency over a broad temperature range such as industrial tires and vibration mounts.

Butyl (IIR, CIIR, AA, BA): The two types of rubber in this category are both based on crude oil. The first is polyisobutylene with an occasional isoprene unit inserted in the polymer chain to enhance vulcanization characteristics. The second is the same, except that chlorine is added (approximately 1.2% by weight), resulting in greater vulcanization flexibility and cure compatibility with general-purpose rubbers.

Butyl rubbers have outstanding impermeability to gases and excellent oxidation and ozone resistance. The chemical inertness is further reflected in lack of molecular-weight breakdown during processing, thus permitting the use of hot-mixing techniques for better polymer/filler interaction.

Flex, tear, and abrasion resistance approach those of natural rubber, and moderate-strength (2,000 psi) unreinforced compounds can be made at a competitive cost. Butyls lack the toughness and durability, however, of some of the general-purpose rubbers.

The attribute responsible for the high-volume use of butyl rubber in automotive inner tubes and tubeless tire interliners is its excellent impermeability to air. Butyls are also used in belting, steam hose, curing bladders, O-rings, shock and vibration products, structural caulks and sealants, water-barrier applications, roof coatings, and gas-metering diaphragms.

Ethylene propylene (EPR, EPDM; AA, BA, CA): Like the butyls, the EP rubbers are of two types. One is a fully saturated (chemically inert) copolymer of ethylene and propylene (EPR); the other (EPDM) is the same as this plus a third polymer building block (diene monomer) attached to the side of the chain. EPDM is chemically reactive and is capable of sulfur vulcanization. The copolymer must be cured with peroxide.

Physical properties of EPR and EPDM are not as good as those obtainable with NR. However, property retention is better than that of NR on exposure to heat, oxidation, or ozone. Bonding is somewhat more difficult, especially with EPR. These materials have broad resistance to chemicals but not to oils and other hydrocarbon fluids. Electrical properties are good.

Typical applications are automotive hose; body mounts and pads; O-rings; conveyor belting; wire and cable insulation and jacketing; window channeling; and other products requiring resistance to weathering. EPDM sheeting, either unsupported or reinforced, is used in roofing and as liners for water conservation and pollution-control systems.

Oil-resistant rubbers

These rubbers include grades suitable for service at temperatures to 250°C and having maximum resistance to oils and greases. Some are considered specialty materials and are quite expensive.

Neoprene (CR; BC, BE): Except for polybutadiene and polyisoprene, neoprene is perhaps the most rubberlike of all, particularly with regard to dynamic response. Neoprenes are a large family of rubbers that have a property profile approaching that of natural rubber, and with better resistance to oils, ozone, oxidation, and flame. They age better and do not soften on heat exposure, although high-temperature tensile strength may be lower than that of NR.

These materials, like NR, can be used to make soft, high-strength compounds. A significant difference is that, in addition to neoprene being more costly than NR by the pound, its density is about 25% greater than that of natural rubber. Neoprenes do not have the low-temperature flexibility of natural rubber, which detracts from their use in low-temperature shock or impact applications.

General-purpose neoprenes are used in hose, belting, wire and cable, footwear, coated fabrics, tires, mountings, bearing pads, pump impellers, adhesives, seals for windows and curtain-wall panels, and flashing and roofing. Neoprene latex is used for adhesives, dip-coated goods, and cellular cushioning jackets.

Chlorinated polyethylene (CM; DE): This family of elastomers is produced by the random chlorination of high-density polyethylene. Because of the high degree of chemical saturation of the polymer chain, the most desirable properties are obtained by crosslinking with the use of peroxides or by radiation. Sulfur donor cure systems are available that produce vulcanizates with only minor performance losses compared to that of peroxide cures. However, the free radical crosslinking by means of peroxides is most commonly used and permits easy and safe processing, with outstanding shelf stability and optimum cured properties.

Chlorinated polyethylene elastomers, sold by the Dow Chemical Co. under the trade name Tyrin, are used in automotive hose applications, premium hydraulic hose, chemical hose, tubing, belting, sheet packing, foams, wire and cable, and in a variety of molded products. Properties include excellent ozone and weather resistance, heat resistance to 300°F (to 350°F in many types of oil), dynamic flexing resistance and good abrasion resistance.

Chlorosulfonated polyethylene (CSM; DE): This material, more commonly known as Hypalon (Du Pont), can be compounded to have an excellent combination of properties including virtually total resistance to ozone and excellent resistance to abrasion, weather, heat, flame, oxidizing chemicals, and crack growth. In addition, CSM has low moisture absorption, good dielectric properties, and can be made in a wide range of colors because it does not require carbon black for reinforcement. Resistance to oil is similar to that of neoprene. Low-temperature flexibility is fair at −40°F.

Hypalon is a special-purpose rubber, not particularly recommended for dynamic applications. It is used generally where its outstanding environmental resistance is needed. Typical applications include coated fabrics, maintenance coatings, tank liners, protective boots for spark plugs and electrical connectors, cable jacketing, and sheeting for pond liners and roofing.

Nitrile (NBR; BF, BG, BK, CH):

The nitriles are copolymers of butadiene and acrylonitrile, used primarily for applications requiring resistance to petroleum oils and gasoline. Resistance to aromatic hydrocarbons is better than that of neoprene but not as good as that of polysulfide. NBR has excellent resistance to mineral and vegetable oils, but relatively poor resistance to the swelling action of oxygenated solvents such as acetone, methyl ethyl ketone, and other ketones. It has good resistance to acids and bases except those having strong oxidizing effects. Resistance to heat aging is good, often a key advantage over NR.

With higher acrylonitrile content, the solvent resistance of an NBR compound is increased but low-temperature flexibility is decreased. Low-temperature resistance is inferior to that of natural rubber, and although NBR can be compounded to give improved performance in this area, the gain is usually at the expense of oil and solvent resistance. As with SBR, this material does not crystallize on stretching, and reinforcing materials are required to obtain high strength. With compounding, nitrile rubbers can provide a good balance of low creep, good resilience, low permanent set, and good abrasion resistance.

Tear resistance is inferior to that of natural rubber, and electrical insulation is lower. NBR is used instead of natural rubber where increased resistance to petroleum oils, gasoline, or aromatic hydrocarbons is required. Uses of NBR include carburetor and fuel-pump diaphragms and aircraft hoses and gaskets. In many of these applications, the nitriles compete with polysulfides and neoprenes.

Epichlorohydrin (CO, ECO; CH): Epichlorohydrin rubber is available as a homopolymer (CO) and a copolymer (ECO) of epichlorohydrin. Reinforced, these rubbers have moderate tensile strength and elongation properties, plus an unusual combination of other characteristics. One of these is low heat buildup, which makes them suitable for applications involving cyclic shock or vibration.

The homopolymer has outstanding resistance to ozone, good resistance to swelling by oils, intermediate heat resistance, extremely low permeability to gases, and excellent weathering properties. This rubber also has low resilience characteristics and low-temperature flexibility only to 5°F — characteristics that may be unsuitable for some applications.

The copolymer is more resilient and has low-temperature flexibility to −40°F, but it is more permeable to gases. Oil resistance of both compounds is about the same. Typical applications include bladders, diaphragms, vibration-control equipment, mounts, vibration dampers, seals, gaskets, fuel hose, rollers, and belting.

Ethylene/acrylic: This family of rubbers is sold by Du Pont, under the trade name of Vamac. Introduced in 1975 in masterbatch form, the family was expanded in 1983 by the addition of a gum polymer. Vamac materials provide, at a moderate price, heat and fluid resistance surpassed by only the more expensive, specialty polymers such as fluorocarbons and fluorosilicones. The material has very good resistance to hot oils, hydrocarbon-based or glycol-based proprietary lubricants, transmission and power-steering fluids. It is not recommended for use with esters, ketones, highly aromatic fluids or high-pressure steam. A special feature of Vamac is its nearly constant damping characteristic over broad ranges of temperature, frequency, and amplitude.

The polymer is recommended for applications requiring a durable, set-resistant rubber with good low-temperature properties and resistance to the combined deteriorating influences of heat, oil, and weather. It is used in various automotive components such as mounts, gaskets, seals, boots, and ignition-wire jackets. Electrical applications include oil-well platform cable jackets, plenum cable, transit-wire jackets, and marine cable.

Perfluoroelastomer (FFKM): Chemical resistance of perfluoroelastomer parts is similar to that of PTFE, and mechanical properties are similar to those of the fluorocarbon rubbers. This high-performance, high-priced rubber, produced by Du Pont as Kalrez, and by Greene, Tweed & Co. as Chemraz, is essentially unaffected by all fluids, including aliphatic and aromatic hydrocarbons, esters, ethers, ketones, oils, lubricants, and most acids. However, some fully halogenated fluids and strong oxidizing acids may cause swelling. The parts are suitable for continuous service to 290°C and intermittent service to 316°C. Resistance to ozone, weather, and flame is exceptional. Radiation resistance is good and high-vacuum performance excellent.

Perfluoroelastomer parts are used primarily in demanding fluid-sealing applications in the chemical-processing, oil-production, aerospace, and aircraft industries.

Acrylate (ACM, ANM; DF, DH): These are specialty rubbers based on polymers of methyl, ethyl, or other alkyl acrylates. They are highly resistant to oxygen and ozone, and their heat resistance is superior to that of all other commercial rubbers except the silicones and the fluorine-containing rubbers. Water resistance is poor, however, so the acrylates are not recommended for use with steam or water-soluble materials such as methanol or ethylene glycol. However, flex life is excellent as is permeability resistance. Resistance to oil swell and deterioration is also excellent at high temperatures.

Low-temperature flexibility is not good, and these rubbers decompose in alkaline solutions and are swelled by acids. Low-temperature flexibility and water resistance can be improved, but only with a marked decrease in heat and oil resistance. These materials are used extensively for bearing seals in transmissions, and for O-rings and gaskets.

Polysulfide (PTR; AK, BK): These polymers have outstanding resistance to oils, greases, and solvents, but they have an unpleasant odor, resilience is poor, and heat resistance is only fair. Abrasion resistance is half that of natural rubber, and tensile strength ranges from 1,200 to 1,400 psi. However, these values are retained after extended immersion in oil.

Basic properties of polysulfide polymers are determined by the type of chain structure and the number of sulfur atoms in the polysulfide groups. Increased sulfur concentration improves solvent and oil resistance, and also reduces permeability to gases. These materials are used in gasoline hose, printing rolls, caulking, adhesives, and binders.

Silicone (VMPQ, PVMQ; MQ, PMQ, FC, FE, GE): Silicone rubber comprises a versatile family of semi-organic synthetics that look and feel like organic rubber, yet have a completely different type of structure from other rubbers. The backbone of the rubber is not a chain of carbon atoms but an arrangement of silicone and oxygen atoms. This structure gives a very flexible chain with weak interchain forces, which provides a remarkably small change in dynamic characteristics over a wide temperature range.

Silicone rubbers have no molecular orientation or crystallization or stretching and must be strengthened by reinforcing materials. The cost of silicone rubbers is not as dependent on petroleum cost as are costs of the synthetic organic rubbers. Although silicones are at the high end of the cost range for rubbers, they can be made to withstand temperatures as high as 600°F without deterioration. At the other end of the scale, silicones retain useful flexibility at −150°F.

While the strength of silicone rubbers is lower than that of other rubbers, these materials have outstanding fatigue and flex resistance. They do not require high tensile strength to serve in dynamic applications. Fall-off in tensile properties with extended exposure to high temperature is much less than for other rubbers. Resistance to chemical deterioration, oils, oxygen, and ozone is also retained under these conditions. Chemical inertness makes these materials well suited for surgical and food-processing equipment. One and two-part silicone sealants are used as structural adhesives and weather-seals in commercial buildings.

Fluorosilicone (FVMQ; FK): This type of silicone provides most of the useful qualities of the regular silicones plus improved resistance to many hydrocarbon fluids such as fuels. Exceptions are ketones and phosphate esters; however, FVMQ rubbers can be blended with conventional dimethyl silicones, which have good resistance to

Rubber selection and service guide

Common or trade name	Natural rubber	Synthetic natural	GRS or Buna S	Polybutadiene	Butyl	Chlorobutyl	EP	EPDM	Neoprene
Chemical type	Natural polyisoprene	Isoprene	Styrene butadiene	Butadiene	Isobutene isoprene	Chlorinated isobutene isoprene	Ethylene propylene	Ethylene propylene diene monomer	Chloroprene
ASTM D1418 Designation	NR	IR	SBR	BR	IIR	CIIR	EPM	EPDM	CR
ASTM D2000/ SAE J200 type, class	AA	AA	AA-BA	AA	AA, BA	AA, BA	AA, BA, CA	AA, BA, CA	BC, BE
PHYSICAL									
[1]Density (gm/cm^3)	0.93	0.93	0.94	0.94	0.92	0.92	0.86	0.86	1.24
Hardness range (Shore A)	30-100	40-80	40-100	45-80	30-100	30-100	40-90	30-90	40-95
Permeability to gases	C	C	C	C	A	A	C	C	B
Electrical resistivity	A	A	A	A	A	A	A	A	C
Odor	B-A	B	B	B	B	B	B	B	B
Taste	C-B	C-B	C-B	C-B	C-B	C-B	B	B	C-B
Nonstaining	A	A	D-B	B	B	B	B	B	B-A
Bondability	A	A	A	A	C	A	C	B	A
MECHANICAL									
[2]Tensile strength (max psi)	4,500	4,000	3,500	3,000	3,000	3,000	3,000	3,000	4,000
[3]Abrasion resistance	A	A	A	A	B	B	B	B	B-A
[4]Flex resistance	A	A	B	C	A	A	B	B	B
[5]Tear resistance	A	B	C	B	B	B	D	B	B
[6]Impact resistance	A	A	A	B	B	B	B	B	B
[7]Deformation capacity	A	A	B	B	A	A	B	B	A-B
[8]Elasticity	A	A	B	A	C-B	C-B	C-B	B-A	A-B
[9]Resilience	A	A	B	A	C	C	C	B	A
[10, 11]Creep, stress relaxation	A	B	B	A	C	C-B	C-B	C-B	B
THERMAL									
Recommended maximum continuous temp (°C)	70	70	100	70	100	100	125	145	100
[12]Low-temp flexibility	B	B	C	A	C	C	B	B-A	C
Heat-aging resistance*	B-C	B-C	B	C	B-A	B-A	A	A	B-A
Flame resistance	D	D	D	D	D	D	D	D	B-A
RESISTANCE TO:									
Weather	C-B	C	C-B	C	A	A	A	A	B
Oxygen	B	B	B	B	A	A	A	A	A
Ozone	C-D	C-D	C-D	C-D	A	A	A	A	B
Radiation	B	B	B	D	B	B	B	B	B
Water	A	A	B-A	A	A	A	A	A	B
Steam	B	B	C	B	B-A	B-A	A	A	B
Alkali dil/conc	A/C-B	C-B/C-B	C-B/C-B	C-B/C-B	A/A	A/A	A/A	A/A	A/A
Acid dil/conc	A/C-B	C-B/C-B	C-B/C-B	C-B/C-B	A/A	A/A	A/A	A/A	A/A
[13]Oil, gasoline, kerosene	NR	NR	NR	NR	NR	NR	NR	NR	C
Benzene, toluol	NR	NR	NR	NR	NR	NR	NR	NR	D
[13]Animal, vegetable oils	D-B	D-B	D-B	D-B	B-A	B-A	B	B	B
Oxygenated solvents	B	B	B	B	A	A	B-A	B-A	C
Halogenated solvents	NR	NR	NR	NR	NR	NR	NR	NR	D
Alcohol	B-A	B	B	B	B-A	B-A	B-A	B-A	A
Synthetic lubes (diester)	NR	NR	NR	NR	NR	NR	NR	NR	D
Hydraulic fluids									
Silicates	B-A	B-A	B-A	B-A	B-A	B-A	B-A	B-A	B
Phosphates	B	B	B	B	A	A	C	B-A	C

A = Excellent B = Good C = Fair D = Poor NR = Not Recommended

* When aged at recommended maximum continuous temperature.

1. The higher the density, the more rubber is required to make a given part. For example, compare neoprene and natural rubber: Even at the same price per pound, neoprene would be more expensive to use.

2. Although tensile strength per se is not necessarily important, retention of strength at elevated temperatures suggests retention of other mechanical properties as well.

3. Abrasion-resistance ratings apply to a wide range of temperatures as well as types of abrasion (such as rubbing and impingement).

4. A high resistance to crack growth indicates good general durability—necessary where physical abuse is expected.

5. Tear resistance, along with crack-growth resistance, is desirable where physical abuse is expected.

6. Rubbers that strain-crystallize at extreme deformations are much more durable in impact than those that do not. Low-temperature flexibility also helps improve impact performance.

7. A high deformation capacity usually indicates a high fatigue resistance to flexing.

these fluids at temperatures to 300°F. The FVMQ rubbers are most useful where the best in low-temperature flexibility is required in addition to fluid resistance, although resistance to fluids (especially those containing aromatics) is poorer than that of the FKM-type fluorocarbon rubbers.

Fluorosilicone rubbers have moderate dielectric properties, low compression set, and excellent resistance to ozone and weathering. They are expensive and definitely special purpose. Typical applications include seals, tank linings, diaphragms, O-rings, and protective boots in electrical equipment.

Fluorocarbon (FKM; HK): Generally produced as a copolymer of vinylidene fluoride and hexafluoropropylene, the fluorocarbons are high-performance, high-cost rubbers known generally as Viton (Du Pont) and Fluorel (3M). These rubbers have outstanding resistance to heat and to many chemicals, oils, and solvents compared to any other commercial rubber. In air, fluorocarbon rubber parts retain at least half of their original properties after 16-hr exposure at

Tyrin	Hypalon	Nitrile or Buna N	Epichloro-hydrin	Acrylate	Thiokol	Silicone	Vamac	Kalrez	Fluoro-silicone	Fluoro-carbon	Urethane
Chlorinated polyethylene	Chlorosulfonated polyethylene	Nitrile butadiene	Epichloro-hydrin	Polyacrylate	Polysulfide	Poly-siloxane	Ethylene/acrylic	Perfluoro-elastomer	Fluoro vinyl methyl siloxane	Fluorinated hydrocarbon	Polyester or polyether urethane
CM	CSM	NBR	CO, ECO	ACM, ANM	PTR	VMQ, PVMQ, MQ, PMQ		FFKM	FVMQ	FKM	BG
BC, BE, CE, DE	CE, DE	BF, BG, BK, CH	CH	DE, DH	AK	FC, FE, GE	EF (proposed)		FK	HK	AU, EU
1.08-1.28	1.08-1.27	1.00	1.36-1.27	1.10	1.34	1.07-1.7	1.08-1.12	2.01	1.35-1.65	1.4-1.95	1.05-1.30
40-100	40-95	20-90	40-90	40-90	20-80	25-80	40-95	65-95	35-80	60-90	35-100
B-A	B	B-A	A	B	D	D	A-B	C	D	A	B
C-B	B	D-C	C-B	B	C	A	B	B	B	B	B
A	B	B	C-B	C-B	D	A-B	B	B	B	B	B
B-A	C-B	C-B	C-B	C-B	D-C	A-B	C-B	B	B	C-B	B
A	A	C-B	B	B	D-B	A	B	C-B	A	C-B	B
A	A	B-A	C-A	B	C-B	B-A	A	C-D	B-A	C-B	C-B
4,000	4,000	3,500	2,500	2,500	50-1,500	600-1,500	2,500	2,000	800-1,400	2,500	5,000-8,000
B	B	A	C-B	C-B	D	C	B-A	B	D	B	A
A	C-B	B	B	B	D	B	B	B-B	D	B	A
B	C-B	B	C-B	C	D	B	C-B	C-B	C	B	A
B	C-B	C	C-A	D	D	C	B	B	C	B	B-A
A	B	B	C-A	C	B	A	B	C	C	C	B
A-B	C-B	B	C	B	D	B-A	C-B	B	B	B-A	C
C	C	B	C-B	C-B	C	D-A	C	C	C	C	C-A
C	C	B	B	C	D	C-A	B	B	B	B	C-A
150	135	100-125	125	150	70	200-240	170	290	200	250	100
B	B	C	C	D	C	A	B	D	B	D	C
B-A	B-A	B	B-A	A	C-B	A	A	A	A	A	B-A
B-A	B-A	D	B-D	D	D	A	C	A	A	A	D
A	A	C-B	B	A	B	A	A	A	A	A	A
A	A	B	B	A	B	A	A	A	A	A	B
A	A	C-D	A	B	A	A	A	A	A	A	A
B	B	B	C-D	B	C	C-B	B	B	C-B	C-B	B
B	B	A	B	D	B	A	B	A	A	A	C-B
B	B	C-B	NR	B-C	D	C-B	C	B	C-B	B	D
A/A	A/A	B/B	B/D	C/C	B/B	A/B	A/A	A/A	A/B	B/C	B/D
A/A	A/A	B/B	B/C	C/C	C/NR	B/C	B/C	A/A	B/C	A/A	C/D
B	B	A	B-A	A	A	D-B	D	A	A	A	C
C-D	C-D	B	B-A	C-B	C-B	NR	C	A	B-A	A	A
B	B	B	A	B	A	A	B-A	A	A	A	D
D	D	D	C	D	A	B-C	D	A	D	NR	C-B
D	D	C-B	A	B	C-A	NR	D	A	B-A	A	B
A	A	C-B	C-B	D	B	C-A	A	A	B-A	C-A	D
C	D	B-A	B	D-C	C-B	NR	C	A	A	A	
B-A	B	B	B	B	D-C	D	NR	A	B	C	C
A	C	D	NR	D	D-C	B	NR	A	D	D	D

8. The lower the permanent set, the better the structural integrity and the better the retention of initial dimensions.

9. The higher the resilience, the less the degradative heat buildup in a flexing or dynamic situation.

10. The better the resistance to creep, the longer the life of the part, particularly where clearances or seals are to be maintained.

11. Resistance to stress relaxation is essential in seals and other components under steady stress in service.

12. Good low-temperature flexibility is a must for most shock absorbers. The first jolt is critical, regardless of subsequent softness.

13. Degradation by oils and greases is essentially a surface effect; parts with poor resistance to these substances but that have appreciable bulk will not be degraded by such exposure.

Basic data, Chemical Products Group, Lord Corp., Erie, PA, with additions by DuPont Co. and Dow Chemical Co.

600°F. These same compounds offer low-temperature stability to −40°F.

In the reinforced state, these rubbers offer moderate tensile strength but relatively low elongation properties. They resist oxidation and ozone, and they do not support combustion. Several versions are available, and conventional compounding produces formulations within a hardness range of 65 to 95 Shore A. Fluorocarbon rubbers are severely attacked by highly polar fluids such as ketones, hydrazine, anhydrous ammonia, and Skydrol (phosphate ester) hydraulic fluids. Postcuring is required to develop optimum properties. Typical applications are seals, gaskets, diaphragms, pump impellers, tubing, and vacuum and radiation equipment.

Urethane (AU, EU; BG): These rubbers, combinations of polyesters or polyethers and diisocyanates, are unusual in that physical properties do not depend on compounding materials. Urethanes crosslink and undergo chain extension to produce a wide variety of compounds. They are available as castable or liquid materials and as solids or millable gums.

Urethane polymers have outstanding abrasion resistance, excellent tensile strength and load-bearing capacity, and elongation potential, accompanied by high hardness. Other properties include low-temperature resistance, high tear strength, either high or low coefficient of friction, good radiation resistance, and good elasticity and resilience, even in very hard stocks.

Typical applications include seals, bumpers, metal-forming dies, valve seats, liners, coupling elements, rollers, wheels, and conveyor belts, especially where abrasive conditions are present.

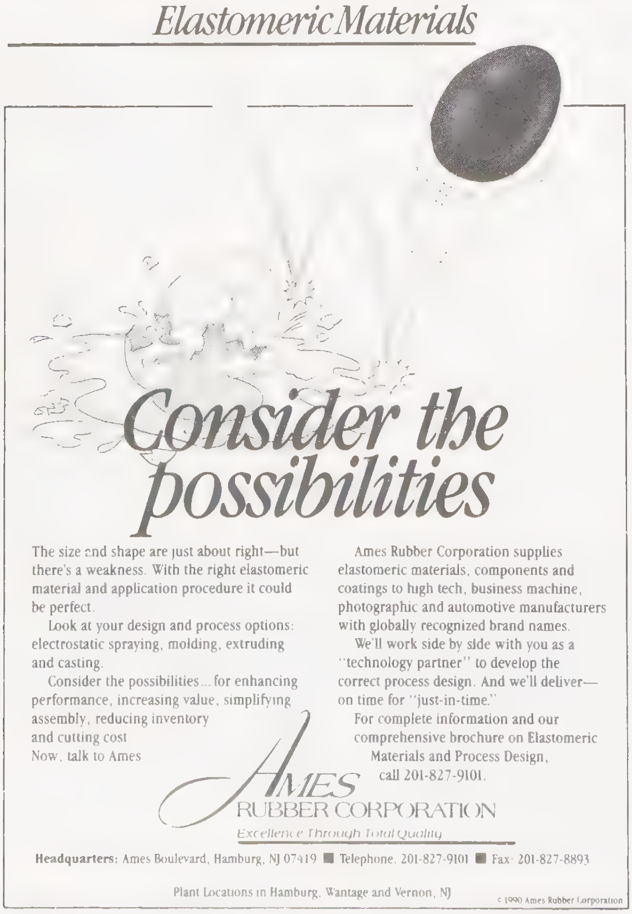
Thermoplastic elastomers

Thermoplastic elastomers (TPEs) have two big advantages over the conventional thermoset (vulcanized) types — processing ease and speed. Other compelling reasons for considering the TPEs are recyclability of scrap, lower energy costs for processing, and the availability of standard, uniform grades (not available in thermosets). This last advantage is particularly important to multinational corporations.

The TPEs are molded or extruded on standard plastics-processing equipment in considerably shorter cycle times than those required for compression or transfer molding of conventional rubbers. They are made by copolymerizing two or more monomers, using either block or graft polymerization techniques. One of the monomers develops the hard, or crystalline, segment that functions as a thermally stable component (which softens and flows under shear, as opposed to the chemical crosslinks between polymeric chains in a conventional, thermosetting rubber); the other monomer develops the soft, or amorphous segment, which contributes the rubbery characteristic.

Properties can be controlled by varying the ratio of the monomers and the lengths of the hard and soft segments. Block techniques create long-chain molecules that have various sequences, or blocks, of hard and soft segments; graft methods involve grafting one polymer chain to another as branches. Graft techniques offer more possibilities to vary the copolymer because both the backbone monomer and the grafted branches can be rubbery, glassy hard, or somewhere between. In general, environmental and fluid resistance are totally predictable.

The four oldest thermoplastic elastomer types are polyurethanes, polyester copolymers, styrene copolymers, and the olefinics. Mechanical properties of the first two types are generally higher than those of the last two. Dynamic properties, such as flex life are also gen-


Elastomeric Materials

Consider the possibilities

The size and shape are just about right—but there's a weakness. With the right elastomeric material and application procedure it could be perfect.

Look at your design and process options: electrostatic spraying, molding, extruding and casting.

Consider the possibilities... for enhancing performance, increasing value, simplifying assembly, reducing inventory and cutting cost. Now, talk to Ames

Ames Rubber Corporation supplies elastomeric materials, components and coatings to high tech, business machine, photographic and automotive manufacturers with globally recognized brand names.

We'll work side by side with you as a "technology partner" to develop the correct process design. And we'll deliver—on time for "just-in-time."

For complete information and our comprehensive brochure on Elastomeric Materials and Process Design, call 201-827-9101.

AMES RUBBER CORPORATION
Excellence Through Total Quality

Headquarters: Ames Boulevard, Hamburg, NJ 07419 ■ Telephone: 201-827-9101 ■ Fax: 201-827-8893

Plant Locations in Hamburg, Wantage and Vernon, NJ

© 1990 Ames Rubber Corporation

Circle 594

Machine Design
reprints mean business.

Let us put them to work for you.

Reprints of your advertisements and "Machine Design" articles can be used as:

- ☞ *Direct mail to customers and prospects.*
- ☞ *Sales aids for your people in the field.*
- ☞ *Tools to inform stockholders and employees.*
- ☞ *Training aids for new employees.*
- ☞ *Handouts at trade shows and company meetings.*
- ☞ *New product announcements.*
- ☞ *Follow-ups to ad inquiries.*

For more information about this cost-effective way to get your message out to your customers and staff or to place an order, call Linda L. Fouts, reprints manager, at (216) 696-7000.

MACHINE DESIGN is a publication of:
Penton Publishing
1100 Superior Avenue, Cleveland, Ohio 44114

erally better. Newest TPEs are three classes of high-performance materials. One is based on polyamide (nylon) chemistry; another, called elastomeric alloys, consists of polymer alloys of an olefinic resin and rubber. The third group, melt-processible rubbers, are sold by Du Pont under the Alcryn tradename.

The polyamide TPEs are low-density, high-elongation materials with good solvent and abrasion resistance. They are expected to fill specialty needs in automotive, sports, medical, and electric-electronic equipment. The elastomeric alloys are based on olefins but their proprietary manufacturing methods give them higher properties than the conventional thermoplastic olefins. They are designed to replace thermoset rubbers such as EPDM, nitrile, and neoprene.

Polyurethanes: The first major elastomers that could be processed by thermoplastic methods were the urethanes. Thermoplastic urethanes do not have quite the heat resistance and compression-set resistance of the thermoset types (see chapters on *Thermoset rubber* and *Polyurethane*, but most other properties are similar. They are available in a wide range of hardness grades and in a number of forms, from several manufacturers.

Urethanes are a reaction product of a diisocyanate and long and short chain polyether, polyester, or caprolactone glycols. The polyether types are slightly more expensive and have better hydrolytic stability and low-temperature flexibility than the polyester types. Mechanical properties of the polyester types are generally higher, however. Caprolactones offer a good compromise between the polyether and polyester types.

Abrasion resistance of the urethanes is outstanding among elastomers, low-temperature flexibility is good, oil resistance is excellent to 180°F, and load-bearing capability ranks with the best of the elastomers. Additives can improve dimensional stability or heat resistance, reduce friction, or increase flame retardancy, fungus resistance, or weatherability. Resistance of the polyester types to strong acids, organophosphorous esters, and steam is poor.

Urethane tubing is used for fuel lines, fluid devices, and parts requiring oxygen and ozone resistance. The excellent abrasion resistance of urethanes qualifies them for use in bumpers, gears, rollers, sprockets, cable jackets, chute linings, textile-machinery parts, casters, and solid tires. Other applications include gaskets, diaphragms, shaft couplings, vibration-damping components, conveyor belts, sheeting, bladders, keyboard covers, and films for packaging.

The most recently introduced commercial thermoplastic polyurethanes are polyether aliphatic diisocyanates based on 1,4-butane diol, HMDI, and polytetramethyl-ethylene diol. These lower molecular-weight materials have better color stability to UV radiation and hydrolysis than the conventional grades. The softer grades are used in medical applications (with suitable antioxidants) and as adhesives in security glazing for armored vehicles, prisons, banks, and in aircraft glazing. Other new grades are stabilized for use as wear layers for aircraft wings.

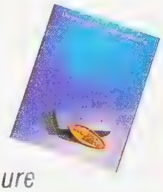
Copolyesters: These thermoplastic elastomers are generally tougher over a broader temperature range than the urethanes. Also, they are easier and more forgiving in processing. Several grades are produced by Du Pont (Hytrel), Hoechst-Celanese (Riteflex), and Eastman Chemical (Ecdel), ranging in hardness from 35 to 72 Shore D. These materials can be processed by injection molding, extrusion, rotational molding, flow molding, thermoforming, and melt

Custom Engineered Elastomer Molding

- *Electronics*
- *Controls*
- *Medical*
- *General*

- Precision tolerance, flash-free.
- Rubber to metal, rubber to plastic.
- Diaphragms with ± .002" tolerance.
- Special elastomer formulas.
- Prototype tooling can be incorporated into multi-cavity production tooling.

Uncompromising Elastomer Molding



Request our 32-page brochure

DA PRO RUBBER, INC.®

Van Nuys, California 91406
8044 Woodley Avenue
(818) 989-4400, FAX (818) 989-6022

Tulsa, Oklahoma 74147
P.O. Box 470175
(918) 258-9386, FAX (918) 258-3286

Circle 595

casting. Powders are also available.

Copolyesters, which along with the urethanes, are high-priced elastoplastics, have excellent dynamic properties, high modulus, good elongation and tear strength, and good resistance to flex fatigue at both low and high temperatures. Brittle temperature is below −90°F, and modulus at −40°F is only slightly higher than at room temperature. Heat resistance to 300°F is good.

Resistance of the copolyesters to nonoxidizing acids, some aliphatic hydrocarbons, aromatic fuels, sour gases, alkaline solutions, hydraulic fluids, and hot oils is good to excellent. Thus, they compete with rubbers such as nitriles, epichlorohydrins, and polyacrylates. However, hot polar materials, strong mineral acids and bases, chlorinated solvents, phenols, and cresols degrade the polyesters. Weathering resistance is low but can be improved considerably by compounding UV stabilizers or carbon blacks with the resin.

Copolyester elastomers are not direct substitutes for rubber in existing designs. Rather, such parts must be redesigned to use the higher strength and modulus, and to operate within the elastic limit. Thinner sections can usually be used — typically one-half to one-sixth that of a rubber part.

Applications of copolyester elastomers include hydraulic hose, fire hose, power-transmission belts, flexible couplings, diaphragms, gears, protective boots, seals, oil-field parts, sports-shoe soles, wire and cable insulation, fiber-optic jacketing, electrical connectors, fasteners, knobs, and bushings.

A copolyester-based thermoplastic elastomer, trademarked Lomod, was introduced by General Electric Plastics in 1985. In addition to general-purpose, flame-retardant and high-heat grades, specific grades have been developed for airdams, fascias, and filler panels with excellent impact resistance down to −40°F and capable of withstanding on-line painting. Lomod thermoplastic elastomers are also used in connectors, wire, cable, hose, tubing, and other applications.

Styrene copolymers: The styrenics are the lowest priced thermoplastic elastomers. They are block copolymers, produced with hard polystyrene segments interconnected with soft segments of a matrix such as polybutadiene, polyisoprene, ethylene-propylene, or ethylene-butylene. These elastomers are available from Shell (Kraton) in several molding and extrusion grades ranging in hardness from 28 to 95 Shore A.

Tensile strength of these materials is lower and elongation is higher than SBR or natural rubber, weather resistance is about the same. Other resistance characteristics can be improved by the addition of resins such as polypropylene or ethylene-vinyl acetate. The styrenic elastoplastics resist water, alcohols, and dilute alkalies and acids. They are soluble in, or are swelled by, strong acids, chlorinated solvents, esters, and ketones. One type has a service temperature limit of 150°F; another grade can be used to 250°F. Both have excellent low-temperature flexibility to −120°F.

Applications for the styrene-butadiene block copolymers include disposable medical products, food packaging, tubing, sheet, belting, mallet heads, and shoe soles. These materials are also used as sealants, hot-melt adhesives, coatings, and for wire and cable insulation.

Olefins: Thermoplastic olefin (TPO) elastomers are available in several grades, having room-temperature hardnesses ranging from 60 Shore A to 60 Shore D. These materials, being based on polyolefins, have the lowest specific gravities of all thermoplastic elastomers. They are uncured or have low levels of crosslinking. Material cost is mid-range among the elastoplastics.

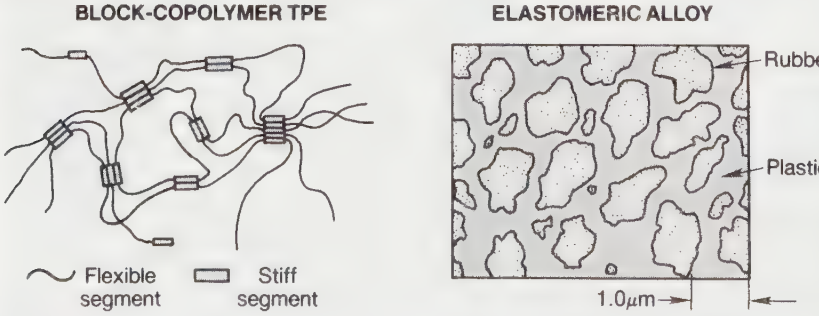
Who's who in TPEs

Producer	Tradename
Urethanes: Hardness range, 65 A to 80 D	
Dow Chemical	Pellethane
Mobay	Texin
K.J. Quinn	Q-Thane
Styrenics: Hardness range, 28 A to 96 A	
Shell	Kraton
Shell	Elexar
Petrofina	Finaprene
Olefinics: Hardness range, 60 A to 60 D	
Monsanto	TPR
Ferro	Ferroflex
Republic Plastics	ETA
Research Polymers	Ren-flex
Teknor Apex	Telcar
Copolyesters: Hardness range, 35 D to 72 D	
DuPont	Hytrel
Eastman	Ecdel
Hoechst-Celanese	Riteflex
General Electric	Lomod
Dutch State Mines	Keltan
Elastomeric alloys: Hardness range 55 A to 50 D	
Monsanto	Santoprene
Monsanto	Geolast
Polyamides: Hardness range, 75 A to 63 D	
Atochem	Pebax
Dow Chemical	Estamid
Emser Industries	Grilamid
Emser Industries	Grilon
Melt processible rubbers: Hardness range, 60A to 80A	
DuPont	Alcryn

These elastomers remain flexible down to −60°F and are not brittle at −90°F. They are autoclavable and can be used at service temperatures as high as 275°F in air. The TPOs have good resistance to some acids, most bases, many organic materials, butyl alcohol, ethyl acetate, formaldehyde, and nitrobenzene. They are attacked by chlorinated hydrocarbon solvents. Compounds rated V-0 by UL 94 methods are available.

Elastomeric alloys: This class of thermoplastic elastomers consists of mixtures of two or more polymers that have received a proprietary treatment to give them properties significantly superior to those of simple blends of the same constituents. The two types of commercial elastomeric alloys are melt-processible rubbers (MPRs) and thermoplastic vulcanizates (TPVs). MPRs have a single-phase; TPVs have two phases.

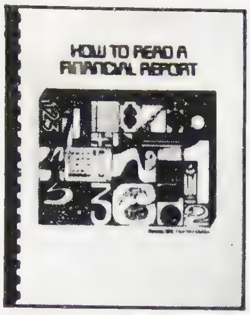
Thermoplastic vulcanizates are essentially a fine dispersion of highly vulcanized rubber in a continuous phase of a polyolefin. Critical to the properties of a TPV are the degree of vulcanization of the rubber and the fineness of its dispersion. The crosslinking and fine dispersion of the rubber phase



The morphology of elastomeric alloys differs from that of block copolymer TPEs. EAs contain a finely dispersed, highly vulcanized rubber phase within a plastic matrix. Particle size helps to determine properties. As particle diameter decreases, properties improve.

HOW TO READ A FINANCIAL REPORT

A self-study course in programmed learning
Review it for 15 days free!



First you'll review the accounting process, tracing the steps from the actual sale to the appearance of the transaction on the financial statements.

Then you'll learn how to use these financial statements to assess financial position and performance of your company through the use of ratio analysis . . . analyzing liquidity, activity, profitability, and coverage ratios.

140 pages . . . spiral bound $24.00

2 - 9 copies	8% discount
10 - 24 "	16% "
25 - 49 "	25% "
50 - 99 "	33% "
100 or more "	40% "

Penton Education Division * 1100 Superior Avenue
Cleveland, Ohio 44114 * 800-321-7003 (In Ohio 216-696-7000

Please send ______ copies of "How to Read a Financial Report" at $______ each. I understand that I may review the course for 15 days and, if not satisfied, I may return it for full refund or credit.

☐ My payment is enclosed for postage-free shipment in the U.S. and Canada.

☐ Bill my company and include shipping and handling charges. My purchase order is enclosed.

Charge my ☐ Visa ☐ MasterCard ☐ American Express card.

Acct. No. ______________ Exp date __________

Name ______________

Company ______________

Address ______________ (Not P.O. Box)

City ______________ State ________ Zip ________

Signature ______________

A practical handbook to help you design today's sophisticated machines —

STANDARD HANDBOOK OF MACHINE DESIGN

By Joseph E. Shigley and Charles R. Mischke

1,632 pages, 929 illustrations, **$124.50**

The entire subject of machine design is presented with emphasis on solving problems that arise daily in engineering design. The wide range of new materials, new components, new processes, and new analytical tools that have brought great changes in the way machines are designed have been covered to permit the design of machines in the future to meet more rigorous standards of reliability, safety, lighter weight, greater speed, and compactness. Use of computer-aided design methods as well as other machine-computation facilities are integrated throughout the handbook and presented in such a manner that future developments in computer hardware and software will not render the contents of the handbook obsolete.

47 GIANT SECTIONS fully cover every aspect of machine design.

To order your copy, complete the coupon below and mail to: Penton Education Division, 1100 Superior Avenue, Cleveland, Ohio 44114 or, for faster service, call 800-321-7003 (In Ohio, call 216-696-7000).

ORDER FORM

Please send me ______ copy(s) of STANDARD HANDBOOK OF MACHINE DESIGN. I understand that I can review it for 15 days and, if not satisfied, return it for full refund or credit.

☐ My payment is enclosed for postage-free shipment in the U.S. and Canada.

☐ Bill my company and include shipping and handling charges. Company purchase order required.

☐ Charge my: ☐ MasterCard ☐ Visa ☐ American Express Card

Account No. ______________ Exp. Date __________

Name ______________

Company ______________

Address (not P.O. Box) ______________

City ______________ State ________ Zip ________

Signature ______________

Penton Education Division • 1100 Superior Avenue • Cleveland, Ohio 44114

SOLVING
A CUSTOM RUBBER COMPONENT PROBLEM
IS EASY.

CALL
MINOR

Minor offers many options for your special custom rubber components including: Molding, Dipping, Extruding, Splicing and Fabrication.

And, they're performance engineered in a broad variety of materials to solve your specific needs–Silicone, Viton, Polyurethane, Neoprene, Natural and all other Synthetic Rubbers. And, we can help your critical deadlines from short runs to large volume.

Call us, we'll immediately solve your custom problems. Sometimes the solution is in our files, already answered.

Write for your catalog today... or CALL TOLL FREE ***1-800-433-6886.***

75TH
1914 MINOR RUBBER 1989
ANNIVERSARY

Minor Rubber Co., Inc.

49 ACKERMAN STREET, BLOOMFIELD, NJ 07003-4299
Phone: 1-201-338-6800 • Fax: 1-201-893-1399 • Telex: 13-8817
•
2425 McIVER LANE, SUITE 180, CARROLLTON, TX 75006-6517
PHONE: 214-484-6477 • FAX: 214-247-3703

Circle 596

gives a TPV high tensile strength (1,100 to 3,900 psi), high elongation (375 to 600%), resistance to compression and tension set, oil resistance, and resistance to flex fatigue. TPVs have excellent resistance to attack by polar fluids and fair-to-good resistance to hydrocarbon fluids. Maximum service temperature is 275°F.

Elastomeric alloys are available in the 55A to 50D hardness range, with ultimate tensile strengths ranging from 800 to 4,000 psi. Specific gravity of MPRs is 1.2 to 1.3; TPV's range is 0.9 to 1.0.

In 1981, Monsanto Chemical Co. commercialized a line of TPVs, called Santoprene, based on EPDM rubber and polypropylene, designed to compete with thermoset rubbers in the middle performance range. ■

Technical assistance for the **Elastomers and rubbers** section was provided by: **Acushnet Rubber Div.**, New Bedford, MA, Rubber; **Dow Chemical Corp.**, Midland, MI, Rubber; **Du Pont Co.**, Wilmington, DE, Rubber, Thermoplastic elastomers; **General Electric Co., Plastics Group**, Pittsfield, MA, Thermoplastic elastomers; **Lord Corp.**, Erie, PA, Rubber; **Minnesota Rubber**, Minneapolis, MN, Rubber; **Monsanto Chemical Co.**, Akron, OH, Thermoplastic elastomers; **Stevens Elastomeric and Plastics Products**, Easthampton, MA, Thermoplastic elastomers.

Thermoplastic elastomers

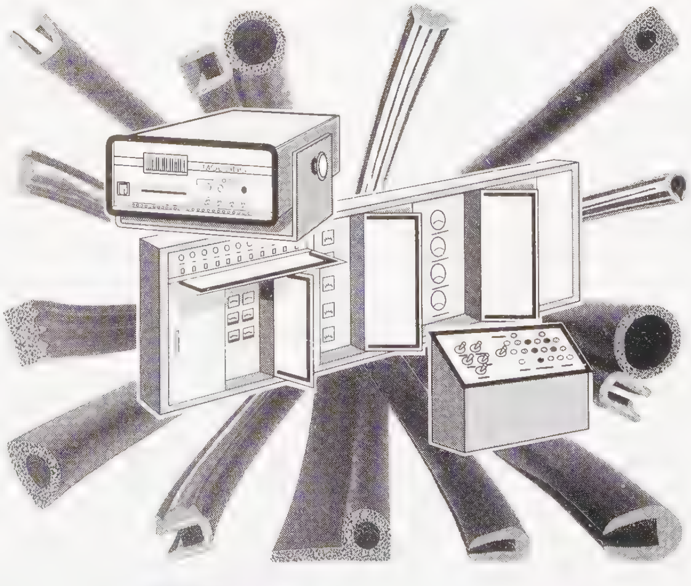
ASTM test	Property	Polyurethane	Copolyester	Styrene block copolymer	Olefin
	PHYSICAL				
D792	**Specific gravity**	1.10-1.24	1.15-1.25	0.93-1.10	0.88-1.00
D792	**Specific volume** (in.^{3}/lb)	26.5-22.0	—	37.4-27.5	31.5-27.7
D570	**Water absorption,** 24 h, ⅛-in. thk (%)	0.1-0.3	0.3-1.6	0.19-0.39	0.01-0.1
	MECHANICAL				
D638	**Tensile strength** (psi)	4,000-9,000	4,490-7,600	300-5,000	650-4,000
D638	**Elongation** (%)	225-570	250-800	250-1,350	180-600
D638	**Tensile modulus** (10^3 psi)	0.7-35	7-75	0.8-50	0.8-34
D790	**Flexural strength** (psi)	600-1,000	—	—	—
D790	**Flexural modulus** (10^3 psi)	—	5-75	4-150	1.5-20
D256	**Impact strength,** Izod (ft-lb/in. of notch)	No break	No break	No break	No break
D785	**Hardness,** Shore	65A-80D	35-72D	28-95A	60A-60D
	THERMAL				
C177	**Thermal conductivity** (10^{-4} cal-cm/sec-cm^2-°C)	5	3.6-4.5	3.6	4.5-5
D696	**Coef of thermal expansion** (10^{-5} in./in.-°F)	5.6-11	2.0-2.8	7.2-7.6	7.2-9.4
D648	**Deflection temperature** (°F)				
	At 264 psi	90	115-122	<75	85-90
	At 66 psi	145	129-284	95	120-180
	ELECTRICAL				
D149	**Dielectric strength** (V/mil) Short time, ⅛-in. thk	450-500	400-460	420-520	400-800
D150	**Dielectric constant** At 1 kHz	6.7-7.5	3.9-5.1	2.5-3.4	2.2-3.1
D150	**Dissipation factor** At 1 kHz	0.050-0.060	0.008-0.02	0.001-0.003	0.0006-0.003
D257	**Volume resistivity** (ohm-cm) At 73°F, 50% RH	2×10^{11}	1.1×10^{12} - 1.8×10^{14}	2.5×10^{16}	$>10^{14}$
D495	**Arc resistance** (s)	122	—	95	>120

TRIMS • MOLDINGS • WEATHERSEALS

Protect and Beautify

All TRIM-LOK® trims, moldings and weatherseals provide a decorative and secure protection against harsh weathering and/or mechanical conditions.

TRIM-LOK® is known for exceptional quality and service. Our products have met the demands of a variety of industries including: aerospace, automotive, marine, motorcycle, lawn and garden equipment.



Dress it Up!

Decorative edge trims and body moldings give that **extra special** sales appeal to your product.

If you have an edge . . We have a trim!

Call today . . . for a ***free*** sample kit and important information on how **TRIM-LOK®** can help you over those rough edges. International Inquiries invited!

(714) 562-0500

FAX: (714) 562-0600

MADE IN THE U.S.A.

INDIVIDUAL METAL CLIPS INSIDE RETAIN PERMANENT GRIP

TRIM-LOK®

TRIM-LOK® Inc. • 6855 Hermosa Circle • Buena Park, CA 90622-6180

"Over 20 years of quality and service in every inch of our product"

Circle 597

Nonferrous metals

Nonferrous metals offer a wide variety of mechanical properties and material characteristics.

In addition to property variations, nonferrous metals and alloys differ in cost, based on availability, abundance, and ease of converting the metal into useful forms. Although magnesium is the most abundant metal on earth, for example, costly processing makes it several times more expensive than the most easily produced metal, iron.

Material selection for a mechanical or structural application requires some important considerations, including how easily the material can be shaped into a finished part and how its properties can be either intentionally or inadvertently altered in the process. Depending on the end use, metals can be simply cast into the finished part, or cast into an intermediate form, such as an ingot, then worked, or wrought, by rolling, forging, extruding, or other deformation process. Although the same operations are used with ferrous as well as nonferrous metals and alloys, the reaction of nonferrous metals to these forming processes is often more severe. Consequently, properties may differ considerably between the cast and wrought forms of the same metal or alloy.

To shape both nonferrous and ferrous metals, designers use processes that range from casting and sintered powder metallurgy (P/M) to hot and cold working. Each forming method imparts unique physical and mechanical characteristics to the final component.

Aluminum

Besides a high strength-to-weight ratio and good formability, aluminum also possesses its own anticorrosion mechanism. When exposed to air, aluminum does not oxidize progressively because a hard, microscopic oxide coating forms on the surface and seals the metal from the environment. The tight chemical oxide bond is the reason why aluminum is not found in nature; it exists only as a compound.

Aluminum and its alloys, numbering in the hundreds, are available in all common commercial forms. Aluminum-alloy sheet can be formed, drawn, stamped, or spun. Many wrought or cast aluminum alloys can be welded, brazed, or soldered, and aluminum surfaces readily accept a wide variety of finishes, both mechanical and chemical. Because of their high electrical conductivity, aluminum alloys are used as electrical conductors. Aluminum reflects radiant energy throughout the entire spectrum, is nonsparking, and nonmagnetic.

Though light in weight, commercially pure aluminum has a tensile strength of about 13,000 psi. Cold working the metal approximately doubles its strength. In other attempts to increase strength, aluminum is alloyed with elements such as manganese, silicon, copper, magnesium, or zinc. The alloys can also be strengthened by cold working. Some alloys are further strengthened and hardened by heat treatments. At subzero temperatures, aluminum is stronger than at room temperature and is no less ductile. Most aluminum alloys lose strength at elevated temperatures, although some retain significant strength to 500°F.

Wrought aluminum: A four-digit number that corresponds to a specific alloying element combination usually designates wrought aluminum alloys. This number is followed by a temper designation that identifies thermal and mechanical treatments.

To develop strength, heat-treatable wrought alloys are solution heat treated, then quenched and precipitation hardened. Solution heat treat-

DESIGNATIONS FOR ALUMINUM FINISHES

The Aluminum Association, in their specification "Designation System for Aluminum Finishes," classifies aluminum finishes according to the following designations:

M—Mechanical finishes
M1X—As-fabricated surface.
M2X—Buffed surface, usually bright and shiny.
M3X—Directionally textured. Finish has a distinct pattern with features lying predominantly in one direction, as produced by a grinding wheel.
M4X—Nondirectionally textured. Finish has a distinct but random pattern, as produced by grit blasting or shot peening, for example.
C—Chemical finishes
C1X—Nonetch cleaned, usually with chemical cleaners, to prepare surfaces for further finishing.
C2X—Etched surface, including chemical milling.
C3X—Brightened. Some aluminum alloys can be brightened to a high luster, but are often clear anodized afterwards.
C4X—Conversion coatings, including chromates, phosphates.
A—Anodic coatings
A1X—General. Includes sulfuric, chromic, and hard anodize.
A2X—Protective and decorative. Generally "jewelry" type coatings below 0.4 mil thickness.
A3X—Architectural Class II—coatings between 0.4 and 0.7 mil thick.
A4X—Architectural coatings. Class I—coatings over 0.7 mil thick.
R—Resins and other organic coatings, including paints, vinyl coatings, epoxies, and fluorocarbons. Powder coatings and fluidized-bed plastic coatings are also included.
V—Viteous coatings, including porcelainizing and ceramics.
E—Electroplating and other metal coatings.

ment consists of heating the metal, holding at temperature to bring the hardening constituents into solution, then cooling to retain those constituents in solution. Precipitation hardening after solution heat treatment increases strength and hardness of these alloys.

While some alloys age at room temperature, others require precipitation heat treatment at an elevated temperature (artificial aging) for optimum properties. However, distortion and dimensional changes during natural or artificial aging can be significant. In addition, distortion and residual stresses can be introduced during quenching from the solution heat-treatment cycle. These induced changes can be removed by deforming the metal (for example, stretching).

Wrought aluminum alloys are also strengthened by cold working. The high-strength alloys — either heat treatable or not — work harden more rapidly than the lower-strength, softer alloys and so may require annealing after cold working. Because hot forming does not always work harden aluminum alloys, this method is used to avoid annealing and straightening operations; however, hot forming fully heat-treated materials is difficult. Generally, aluminum formability increases with temperature.

Recently developed aluminum alloys can provide nearly custom-engineered strength, fracture toughness, fatigue resistance, and corrosion resistance for aircraft forgings and other critical components. The rapid-solidification process is the basis for these new alloy systems, called wrought P/M alloys. The term wrought P/M is used to distinguish this technology from conventional press-and-sinter P/M technology. Grades 7090 and 7091 are the first commercially available wrought P/M aluminum alloys. These alloys can be handled like conventional aluminum alloys on existing aluminum-fabrication facilities.

Other significant new materials are the aluminum-lithium alloys. These lightweight metals are as strong as alloys now in use and can be fabricated on existing metalworking equipment. Although impressive structural weight reductions (from 7 to 10%) are possible through direct substitution, even greater reduction (up to 15%) can be realized by developing fully optimized alloys for new designs. Such alloys would be specifically tailored to provide property combinations not presently available. Producing an alloy that will provide these combinations is the object of second and third-generation low-density alloy development efforts.

Operating economy is still an important consideration in vehicle design despite fluctuating fuel prices. Downsizing to save fuel has reached its practical limits; now, reducing the weight of individual components is taking over. One significant change being implemented by designers of automobiles and military vehicles today is converting driveshafts, radiators, cylinder heads, suspension members, and other structural components to aluminum.

Cast aluminum: Aluminum can be cast by all common casting processes. Aluminum casting alloys are identified with a unified, four-digit (xxx.x) system. The first digit indicates the major alloying element. For instance, 100 series is reserved for 99% pure aluminum with no major alloying element used.

Wrought aluminum alloy designations

Major alloying element	Designation
Aluminum (99% or greater)	1xxx
Copper	2xxx
Manganese	3xxx
Silicon	4xxx
Magnesium and silicon	6xxx
Zinc	7xxx
Other	8xxx
Unused series	9xxx

The second digit indicates modifications of original alloy or impurity limits.
The last two digits identify the alloy or aluminum or alloy purity.

The second and third digits in the 100 series indicate the precise minimum aluminum content. For example, 165.0 has a 99.65% minimum aluminum content. The 200-900 series designate various aluminum alloys, with the second two digits assigned to new alloys as they are registered. The fourth digit indicates the product form. Castings are designated 0; ingots are designed 1 or 2.

Letter prefixes before the numerical designation indicate special control of one or more elements or a modification of the original alloy. Prefix X designates an experimental composition. The material may retain the experimental designation up to five years. Limits for the experimental alloy may be changed by the registrant.

Commercial casting alloys include heat-treatable and nonheat-treatable compositions. Alloys that are heat treated carry the temper designations 0, T4, T5, T6, and T7. Die castings are not usually solution heat treated because the temperature can cause blistering.

Permanent-mold casting technology involves several variations having to do with how the metal gets into the mold cavity. Initially, molds were simply gravity filled from ladles, in the same manner as sand molds. Subsequently, low pressure on the liquid-metal surface of a crucible was used to force the metal up, through a vertical tube, into the mold cavity. This refinement produces castings with higher mechanical properties and is more economical than gravity filling because extensive gates and risers are unnecessary.

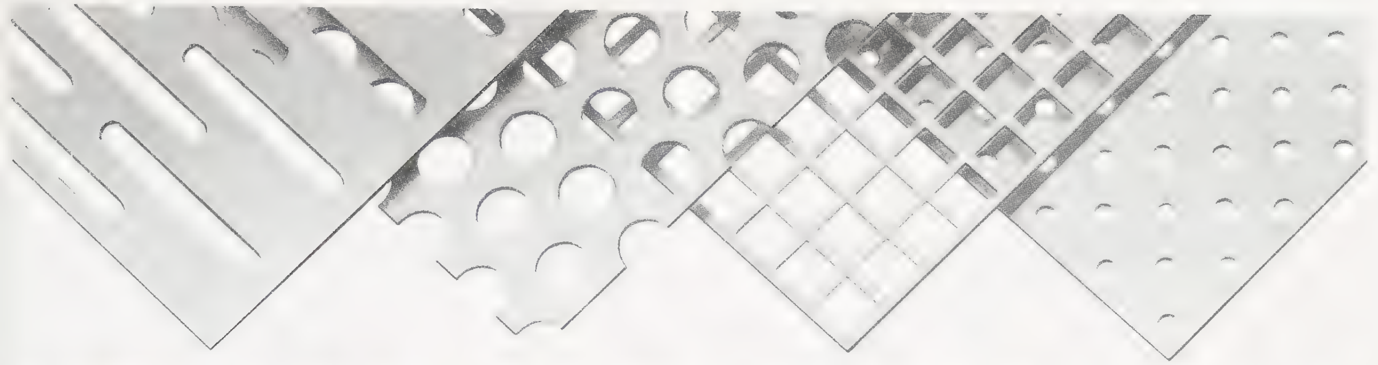
More recently, the process was modified to use a low level of vacuum drawn on the mold cavity, causing atmospheric pressure to force the molten metal up into the mold. This process variation, together with controlled and rapid solidification, increases properties further because it produces castings that are almost entirely free of porosity. Although both variations improve properties and speed casting cycles, the added equipment complexities limit the casting size that can be handled. Consequently, all three permanent-mold processes are in use today, turning out aluminum castings weighing from less than one pound to several hundred pounds.

Aluminum matrix composites: Metal matrix composites (MMCs) consist of metal alloys reinforced with fibers, whiskers, particulates, or wires. Alloys of numerous metals (aluminum, titanium, magnesium and copper) have been used as matrices to date.

Recent MMC developments, however, seem to thrust aluminum into the spotlight. In the NASA space shuttle, for example, 240 struts are made from aluminum reinforced with boron fibers. Also, aluminum diesel-engine pistons that have been locally reinforced with ceramic fibers are eliminating the need for wear-resistant nickel-cast iron inserts in the automotive environment.

Fabrication methods differ for both products. Monolayer tapes in the space shuttle struts are wrapped around a mandrel and hot isostatically pressed to diffusion bond the layers. For the pistons, a squeeze-casting process infiltrates liquid metal into a fiber preform under pressure. Other fabrication methods for MMCs include: hot pressing a layer of parallel fibers between foils to create a monolayer tape; creep and superplastic forming in a die; and spraying metal plasmas on collimated fibers followed by hot pressing.

Superplastic aluminum: Superplastic forming of metal, a process similar to vacuum forming of plastic sheet, has been used to form low-strength aluminum into nonstructural parts such as cash-register housings, luggage compartments for passenger trains, and



WE MAKE BUYING PERFORATED A HOLE LOT EASIER!

MORE SELECTION H&K has the industry's largest library of stock dies. So you'll save time and money by eliminating the need for custom tooling.

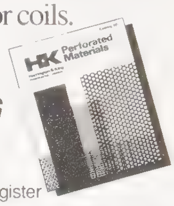
BETTER SERVICE In addition to fast, accurate quotes, we can provide technical data on material strength, air flow, noise and EMI suppression. Often we can make suggestions on how you could save money on your material or fabricating costs.

FASTER DELIVERY We operate two plants for custom orders. Or if you *really* need holes in a hurry, call one of our 8 regional warehouses for same-day shipment of stock sheets or coils.

Harrington & King
PERFORATING COMPANY

5655 Fillmore St., Chicago IL 60644 800/621-3869 Fax 312/261-1686
15 Essex Road, Paramus NJ 07652 800 638-1801 Fax 201/368-2257
3939 Michigan, Cleveland TN 37311 800/251-6026 Fax 615/479-8694

FREE CATALOG
Call toll-free
800/621-3869
or see Thomas Register



Circle 598

Machine Design
reprints mean business

Let us put them to work for you.

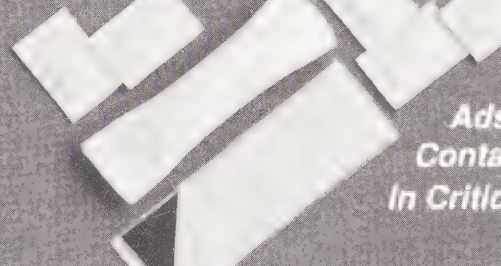
Reprints of your advertisements and "Machine Design" articles can be used as:

- ☞ *Direct mail to customers and prospects.*
- ☞ *Sales aids for your people in the field.*
- ☞ *Tools to inform stockholders & employees.*
- ☞ *Training aids for new employees.*
- ☞ *Handouts at trade shows and company meetings.*
- ☞ *New product announcements.*
- ☞ *Follow-ups to ad inquiries.*

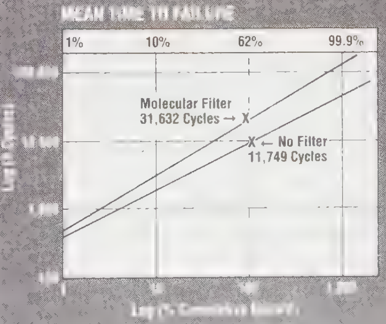
For more information about this cost-effective way to get your message out to your customers and staff or to place an order, call Linda L. Fouts, reprints manager, at (216), 696-7000.

MACHINE DESIGN is a publication of:
Penton Publishing
1100 Superior Avenue
Cleveland, Ohio 44114

MOLECUSORB®



Adsorbs Molecular Contaminants & Moisture In Critical Environments!*



- Protects sensitive surfaces from corrosive vapors, sub-micron molecules, and moisture.
- Features new, higher performance carbons with safer, next-generation barriers.
- Available in any size or shape to meet rigid design requirements.

*CALL OR WRITE FOR INDEPENDENT TEST LAB DATA

ALFCO
Air Filtration Specialists
1690 Cindy Lane, Carpinteria, CA 93013-2908 • PHONE: (805) 684-7651 • FAX: (805) 684-3054

Circle 599

nonload-bearing aircraft components. New in this area of technology is a superplastic-formable high-strength aluminum alloy, now available for structural applications and designated 7475-02. Strength of alloy 7475 is in the range of aerospace alloy 7075, which requires conventional forming operations. Although initial cost of 7475 is higher, finished part cost is usually lower than that of 7075 because of the savings involved in the simplified design/assembly.

Beryllium

Beryllium—mechanical properties

	HOT-PRESSED BLOCK Standard grade	Structural grade	Instrument grade	Isostatically pressed block or shapes	Cross-rolled sheet 0.020-0.025 in.	Extru rod
Tensile yield strength (10^3 psi)	35	30	40	35	50	50
Tensile strength (10^3 psi)	47	42	55	50	70	90
Elongation in 2 in. (%)	2	3	2	3.0	10.0	10.0
Modulus of elasticity (10^6 psi)				44		

Beryllium—physical properties

Melting temperature (°F)	2,345
Coefficent of thermal expansion (in./in.-°F)	6.4×10^{-6}
Specific heat (Btu/lb-°F)	0.46
Thermal conductivity (Btu-ft/h-ft^2-°F)	
70°F	105
1,600°F	48
Density (lb/in.^{3})	0.066
Electrical resistivity (microhm-cm)	5

Among structural metals, beryllium has a unique combination of properties. It has low density (two-thirds that of aluminum), high modulus per weight (five times that of ultrahigh-strength steels), high specific heat, high strength per density, excellent dimensional stability, and transparency to X-rays. Beryllium is expensive, however, and its impact strength is low compared to values for most other metals.

Available forms include block, rod, sheet, plate, foil, extrusions, and wire. Machining blanks, which are machined from large vacuum hot pressings, make up the majority of beryllium purchases. However, shapes can also be produced directly from powder by processes such as cold-press/sinter/coin, CIP/HIP, CIP/sinter, CIP/hot-press and plasma spray/sinter. (CIP is cold-isostatic press, and HIP is hot-isostatic press.) Mechanical properties depend on powder characteristics, chemistry, consolidation process, and thermal treatment. Wrought forms, produced by hot working, have high strength in the working direction, but properties are usually anisotropic.

Beryllium parts can be hot formed from cross-rolled sheet and plate as well as plate machined from hot-pressed block. Forming rates are slower than for titanium, for example, but tooling and forming costs for production items are comparable.

Structural assemblies of beryllium components can be joined by most techniques such as mechanical fasteners, rivets, adhesive bonding, brazing, and diffusion bonding. Fusion-welding processes are generally avoided because they cause excessive grain growth and reduced mechanical properties.

Beryllium behaves like other light metals when exposed to air by forming a tenacious protective oxide film that provides corrosion protection. However, the bare metal corrodes readily when exposed for prolonged periods to tap or seawater or to a corrosive environment that includes high humidity. The corrosion resistance of beryllium in both aqueous and gaseous environments can be improved by applying chemical conversion, metallic, or nonmetallic coatings. Beryllium can be electroless nickel plated, and flame or plasma sprayed.

All conventional machining operations are possible with beryllium, including EDM and ECM. However, beryllium is toxic if inhaled. Since airborne beryllium particles and beryllium salts present a health hazard, the metal must be machined in specially equipped facilities for safety.

Machining damages the surface of beryllium parts. Strength is reduced by the formation of microcracks and "twinning." The depth of the damage can be limited during finish machining by taking several light machining cuts and sharpening cutting tools frequently or by using nonconventional metal-removal processes. For highly stressed structural parts, 0.002 to 0.004 in. should be removed from each surface by chemical etching or milling after machining. This process removes cracks and other surface damage caused by machining, thereby preventing premature failure. Precision parts should be machined with a sequence of light cuts and intermediate thermal stress reliefs to provide the greatest dimensional stability.

Beryllium typically appears in military-aircraft and space-shuttle brake systems, in missile reentry body structures, missile guidance systems, mirrors and optical systems, satellite structures, and X-ray windows. The modulus-to-density ratio is higher than that of unidirectionally reinforced, "high-modulus" boron, carbon, and

Aluminum wrought alloys

Designation	1100		2011		2014		2024		2036	2219	
Temper	O	H18	T3	T8	O	T6	O	T4	T4	O	T62
Yield strength (10^3 psi)	5	22	43	45	14	60	11	47	28	11	42
Tensile strength (10^3 psi)	13	24	55	59	27	70	27	68	49	25	60
Shear strength (10^3 psi)	9	13	32	35	18	42	18	41	30	—	—
Fatigue limit (10^3 psi)	5	9	18	18	13	18	13	20	18	—	15
Elongation in 2 in (%)	45	15	15	12	18	13	22	19	24	—	—
Modulus of elasticity (10^6 psi)	10.0	10.0	10.2	10.2	10.6	10.6	10.6	10.6	10.3	10.6	10.6
Melting temperature (°F)	1,190-1,215	1,190-1,215	1,005-1,190	1,005-1,190	945-1,080	945-1,080	935-1,180	935-1,180	1,030-1,200	1,010-1,190	1,010-1,190
Coefficient of thermal exp (10^{-6} in./in.-°F)	13.1	13.1	12.7	12.7	12.8	12.8	12.9	12.9	13.0	12.4	12.4
Thermal conductivity (Btu-in./h-ft^2-°F)	1,540	1,510	1,050	1,190	1,340	1,070	1,340	840	1,100	1,190	840
Electrical resistivity (Ohm-cir mil/ft)	18	18	27	23	21	26	21	35	25	24	35

graphite-fiber composites. Beryllium has an additional advantage because its modulus of elasticity is isotropic.

Copper

Copper provides a diverse range of properties: good thermal and electrical conductivity, corrosion resistance, ease of forming, ease of joining, and color. By volume, copper has the highest electrical conductivity of all metals except pure silver. In addition, however, copper and its alloys have relatively low strength-to-weight ratios and low strengths at elevated temperatures. Some copper alloys are also susceptible to stress-corrosion cracking unless they are stress relieved.

Copper and its alloys — the brasses and bronzes — are available in rod, plate, strip, sheet, tube shapes, forgings, wire, and castings. These metals are grouped according to composition into several general categories: coppers, high-copper alloys, brasses, leaded brasses, bronzes, aluminum bronzes, silicon bronzes, copper nickels, and nickel silvers.

Copper-based alloys form adherent films that are relatively impervious to corrosion and that protect the base metal from further attack. Certain alloy systems darken rapidly from brown to black in air. Under most outdoor conditions, however, copper surfaces develop a blue-green patina. Lacquer coatings can be applied to retain the original alloy color. An acrylic coating with benzotriazole as an additive lasts several years under most outdoor, abrasion-free conditions.

Although they work harden, copper and its alloys can be hot or cold worked. Ductility can be restored by annealing or heating incident to welding or brazing operations.

For applications requiring maximum electrical conductivity, the most widely used copper is C11000, "tough pitch," which contains approximately 0.03% oxygen and a minimum of 99.0% copper. In addition to high electrical conductivity, oxygen-free grades C10100 and C10200 provide immunity to embrittlement at high temperature. The addition of phosphorus produces grade C12200 — the standard water-tube copper.

High-copper alloys contain small amounts of alloying elements that improve strength with some loss in electrical conductivity. In amounts of 1%, for example, cadmium increases strength by 50%, with a loss in conductivity to 85%. Small amounts of cadmium raise the softening temperature in alloy C11600, which is used widely for printed circuits. Tellurium or sulfur, present in small amounts in Grades C14500 and C14700, has been shown to increase machinability.

Copper alloys do not have a sharply defined yield point, so yield strength is reported either as 0.5% extension under load, or as 0.2% offset. On the most common basis (0.5% extension), yield strength of annealed material is approximately one-third the tensile strength. As the material is cold worked or hardened, it becomes less ductile, and yield strength approaches tensile strength.

Copper is specified according to temper, which is established by cold working or annealing. Typical levels are: soft, half-hard, hard, spring, and extra-spring. Yield strength of a hard-temper copper is approximately two-thirds of tensile strength.

For brasses, phosphor bronzes, or other commonly cold-worked grades, the hardest available tempers are also the strongest and represent approximately 70% reduction in area. Ductility is sacrificed, of course, to gain strength. Copper-beryllium alloys can be precipitation hardened to the highest strength levels attainable in copper-base alloys.

The ASME Boiler and Pressure Vessel Code should be used for designing critical copper-alloy parts for service at elevated temperatures. The code recommends that, for a specific service temperature, the maximum allowable design stress should be the lowest of these values as tabulated by the code: one-fourth of the ultimate tensile strength, two-thirds of the yield strength, and two-thirds of the average creep strength or stress-rupture strength under specified conditions. Silicon bronzes, aluminum brasses, and copper nickels are widely used for elevated-temperature applications.

All copper alloys resist corrosion by fresh water and steam. Copper nickels, aluminum brass, and aluminum bronzes provide superior resistance to saltwater corrosion. Copper alloys have high resistance to alkalies and organic acids, but have poor resistance to inorganic acids. One corrosive situation encountered, particularly in the high-zinc alloy, is dezincification. The brass dissolves as an alloy, but the copper constituent redeposits as a porous, spongy metal. Meanwhile, the zinc component is carried away by the atmosphere or deposited on the surface as an insoluble compound.

Designating alloys: Originally developed as a three-digit system by the U.S. copper and brass industry, the designation system for copper-based alloys has been expanded to five digits preceded by the letter C as part of the Unified Numbering System for Metals and Alloys (UNS). The UNS designations are simply an expansion of the former designation numbers. For example, Copper Alloy No. 377 (forging brass) becomes C37700. Numbers C10000 through C79900 are assigned to wrought compositions, and numbers C80000 through C99900 to casting alloys.

The designation system is not a specification; rather, it is a method for identifying and defining the chemical composition of mill and foundry products. The precise requirements to be satisfied by a material and the temper no-

3003		3004		5052		5083		6061		6066		6262	7050	7075
O	H18	O	H38	O	H38	O	H321	O	T6	O	T6	T9	T74	T6
6	27	10	36	13	37	21	33	8	40	12	52	55	70	73
16	29	26	41	28	42	42	46	18	45	22	57	58	81	83
11	16	16	21	18	24	25	—	12	30	14	34	35	45	48
7	10	14	16	16	20	—	23	9	14	—	16	13	21	23
40	10	25	6	30	8	22	16	30	17	18	12	10	10	11
10.0	10.0	10.0	10.0	10.2	10.2	10.3	10.3	10.0	10.0	10.0	10.0	10.0	10.3	10.4
1,190-1,210	1,190-1,210	1,165-1,210	1,165-1,210	1,125-1,200	1,125-1,200	1,095 1,180	1,095 1,180	1,080-1,205	1,080-1,205	1045-1,195	1045-1,195	1,080-1,205	910-1,165	890-1,175
12.9	12.9	13.3	13.3	13.2	13.2	13.2	13.2	13.1	13.1	12.9	12.9	13.0	12.8	13.1
1,340	1,070	1,130	1,130	960	960	810	—	1,250	1,160	1,070	1,020	1,190	1,092	900
21	26	25	25	30	30	36	—	22	24	26	28	24	35	31

menclature that applies are defined by the relevant standard specifications (ASTM, Federal, and Military) for each composition.

There are approximately 370 commercial copper and copper-alloy compositions. Brass mills make wrought compositions in the form of rod, plate, sheet, strip, tube, pipe, extrusions, foil, forgings, and wire. Foundries supply castings. The following general categories apply to both wrought and cast compositions.

Coppers, high-copper alloys: Both wrought and cast compositions have a designated minimum copper content and may include other elements or additions for special properties.

Brasses: These alloys contain zinc as the principal alloying element and may have other designated elements. The wrought alloys are comprised of copper-zinc alloys, copper-zinc-lead alloys (leaded brasses), and copper-zinc-tin alloys (tin brasses). The cast alloys are comprised of copper-zinc-tin alloys (red, semired and yellow brasses), manganese bronze alloys (high-strength yellow brasses), leaded manganese bronze alloys (leaded high-strength yellow brasses), and copper-zinc-silicon alloys (silicon brasses and bronzes).

Bronzes: Wrought bronze alloys comprise four main groups: copper-tin-phosphorus alloys (phosphor bronzes), copper-tin-lead-phosphorus alloys (leaded phosphor bronzes), and copper-silicon alloys (silicon bronzes). Cast alloys also have four main families: copper-tin alloys (tin bronzes), copper-tin-lead alloys (leaded and high-leaded tin bronzes), copper-tin-nickel alloys (nickel-tin bronzes), and copper-aluminum alloys (aluminum bronzes).

Copper-nickels: These are either wrought or cast alloys containing nickel as the principal alloying element.

Copper-nickel-zinc alloys: These are known as nickel silvers, from their color.

Leaded coppers: These are cast alloys containing 20% lead or more.

Lead

Not only is lead the most impervious of all common metals to X-rays and gamma radiation, it also resists attack by many corrosive chemicals, most types of soil, and marine and industrial environments. Although lead is one of the heaviest metals, only a few applications are based primarily on its high density. Main reasons for using lead often include low melting temperature, ease of casting and forming, good sound and vibration absorption, and ease of salvaging from scrap.

Nearly three-fourths of all U.S. lead consumption is for chemical applications such as paint pigments, gasoline additives, and storage batteries. This chapter, however, discusses only its mechanical applications.

With its high internal damping characteristics, lead is one of the most efficient sound attenuators for industrial, commercial, and residential applications. Sheet lead, lead-loaded vinyls, lead composites, and lead-containing laminates are used to reduce machinery noise. Lead sheet with asbestos or rubber sandwich pads are commonly used in vibration control.

The natural lubricity and wear resistance of lead make the metal suitable, in alloys, for heavy-duty bearing applications such as railroad-car journal bearings and piston-engine crank bearings. Lead is also widely used as a constituent in solders. Most common solders are the lead-tin alloys; melting temperature can be as low as 361°F.

In its unalloyed form (defined by ASTM B29 as 99.85% minimum lead), lead is soft and weak; it requires support for mechanical applications. This "chemical lead" is used primarily in corrosive chemical-handling applications such as tank linings.

"Hard lead" — lead alloyed with 1 to 13% antimony — has sufficient tensile strength, fatigue resistance, and hardness for many mechanical applications. These alloys can be cast, rolled, or extruded and are especially suited for castings requiring good detail and moderate strength. Rolled antimonial alloys are harder and stronger than the cast alloys. Battery-plate lead contains 7 to 12% antimony.

Calcium (0.03 to 0.12%) forms another series of mechanically suitable alloys with lead. These alloys age harden naturally at room temperature — usually for 30 to 60 days — after being cast

Lead alloys

	4% Sb Cast
Density (lb/in^3)	0.398
Yield strength, 2% offset (10^3 psi)	2.7
Tensile Strength (10^3 psi)	5.4
Compressive strength (10^3 psi)	7.2
Fatigue strength (10^3 psi)	2.1
Creep strength, 70°F, 0.2%/yr (10^3 psi)	0.23
Elongation in 2 in (%)	25
Modulus of elasticity (10^6 psi)	3.0
Melting temperature (°F)	—
Electrical resistivity (microhm-cm)	24.0

*Longitudinal direction only. Transverse properties ar

Copper alloys

	WROUGHT ALLOYS							
	Tellurium copper	Beryllium	Copper	Med-leaded brass (65Cu-34Zn)	Free cutting brass	Leaded phos-bronze (88Cu-4Zn)	Aluminum silicon-bronze (91Cu-7Al-2Si)	Silicon bronze (97Cu-3Si)
UNS designation	C14500	C17200	C17000	C34000	C36000	C54400	C64200	C65500
Density (lb/in.^{3})	0.323	0.302	0.304	0.306	0.307	0.321	0.278	0.308
Melting temperature (°F)	1,967	1,800	1,830	1,700	1,650	1,830	1,840	1,880
Coefficient of thermal expansion (10^{-7} in./in.-°F)	95	97	97	113	114	96	100	100
Thermal conductivity (Btu-ft/hr-ft^2-°F)	205	60	60	67	67	50	26	21
Electrical conductivity (% IACS)*	93	22-25	22-25	26	26	19	8	7
Modulus of elasticity (10^6 psi)	17	19	19	15	14	15	16	15
Yield strength (10^3 psi)	10-44	150-200	135-165	19-42	18-45	57-63	35-68	22-60
Tensile strength (10^3 psi)	32-48	175-215	165-200	50-55	49-68	68-75	75-102	58-108
Shear strength (10^3 psi)	22-27	—	—	34-36	30-38	—	59	43-62
Elongation in 2 in. (%)	50-20	5-2	5-2	60-40	53.18	20-15	32-22	60.13
Machinability rating †	85	—	—	70	100	80	60	30

*The accepted value of electrical conductivity for electolytic tough-pitch copper and for oxygen-free copper is 101% IACS (International Annealed Copper Standar

6% Sb Cast	6% Sb Extruded	6% Sb Rolled	10% Sb Cast	0.07% Ca Cast	0.07% Ca Wrought*	0.07% Ca, 0.7% Sn Cast	0.07% Ca, 0.7% Sn Wrought*
0.393			0.382	0.410			
2.8	—	2.2	3.2	—	3.6	—	8.5
6.6	4.5	4.3	7.4	5.4	4.7	7.3	9.0
8.6	—	—	9.8	—	—	—	—
2.5	1.2	1.5	2.7	—	—	—	—
0.25	—	0.40	—	0.50	0.55	—	2.0
22	41	42	16	40	30	40	10
3.5	—	—	4.0	—	—	2.5	
486				623		619	
25.3			27.7	21.8		21.9	

or worked. Properties of wrought Pb-Ca alloys are somewhat directional, being greater in the longitudinal direction. Uses include cable sheathing and grids in storage batteries.

Tin, added to Pb-Ca alloys in amounts to about 1.5%, raises tensile strength and stress-rupture resistance but increases aging time to 180 days. Tin is also used to reduce coefficient of friction for bearing applications. Higher tin-bearing alloys are primarily used in solders, which normally contain from 40 to 60% tin.

Lead alloys are castable by most methods. Intricate details can be reproduced, and the surface can be readily painted. Lead alloys can be extruded into pipes, bars, channels, and rods. Cold-rolled lead sheet is available in thicknesses ranging from foil to 2 in., in widths to 11 ft, and in lengths to 60 ft. Sheet thicknesses are specified by weight: Generally, each 1⁄64 in. of thickness corresponds to 1 lb/ft^2.

Lead often requires support by other materials. For example, lead sheets can be clad or fastened (mechanically or with adhesives) to plastic or steel panels and pipe. Lead-clad steel, in a range of thicknesses, is produced by cold-rolling lead sheet on terne-coated steel. Other clad combinations are produced by spot welding, spraying, hot dipping, and electroplating. These laminates are particularly useful in noise and vibration-absorption applications.

Magnesium

As the lightest structural metal available, magnesium's combination of low density and good mechanical strength results in a high strength-to-weight ratio.

Because of their low modulus of elasticity, magnesium alloys can absorb energy elastically. Combined with moderate strength, this provides excellent dent resistance and high damping capacity. Magnesium has good fatigue resistance and performs particularly well in applications involving a large number of cycles at relatively low stress. The metal is sensitive to stress concentration, however, so notches, sharp corners, and abrupt section changes should be avoided.

Magnesium parts are generally used from room temperature to about 200°F or, in some cases, to 350°F. Some alloys can be used in service environments to 700°F for brief exposures.

Magnesium is widely recognized for its favorable strength-to-weight ratio and excellent castability, but deeply ingrained misconceptions often prevent designers from specifying it as a die-cast material. However, what is true of magnesium as a generic material is not true of today's die-casting alloy. The new high-purity alloy, combined with advances in fluxless, hot-chamber die-casting processing, has altered the traditional guidelines for evaluating the cost and performance of magnesium die castings.

Relative metal weights

Metal	Relative weight	Specific gravity
Magnesium (AZ91D)	1.0	1.8
Aluminum (SC84A)	1.5	2.7
Zinc (AG40A)	3.7	6.6
Cast iron (gray)	3.9	7.0
Tin (ASTM No. 2)	4.1	7.4
Brass (yellow)	4.7	8.4
Bronze (phosphor)	4.9	8.8
Lead (antimonial)	6.1	11.0

Fabrication: Magnesium alloys are the easiest of the structural metals to machine. They can be shaped and fabricated by most metalworking processes, and they are easily welded. At room temperature, magnesium work hardens rapidly, reducing cold formability; thus, cold forming is limited to mild deformation or roll bending around large radii. Pure magnesium is usually alloyed with other elements to develop sufficient strength for structural purposes. Some alloys are heat

CAST ALLOYS									
Manganese bronze	Leaded red brass (85Cu-5Zn-5Sn-5Pb)	Leaded yellow brass	Manganese bronze	Navy M bronze	Leaded Ni-Sn bronze	Bearing bronze	Aluminum bronze	Copper nickel (90Cu-10Ni)	Nickel silver
C67500	C83600	C85200	C86200	C92200	C92900	C93200	C95400	C96200	C97300
0.302	—	—	—	—	—	—	—	—	—
1,650	1,850	1,725	1,725	1,810	1,887	1,790	1,900	2,100	1,904
118	100	115	120	100	95	100	90	95	90
61	41.6	48.5	20.5	40.2	33.6	33.6	33.9	26	16.5
24	15	18	7.5	14.3	9.2	12	13	11	5.7
15	13.5	11	15	14	14	14.5	15.5	18	16
30-60	17	13	48	20	26	18	35-54	25	17
65-84	37	38	95	40	47	35	85-105	45	35
42-48	—	—	180	—	—	—	47-50	—	—
33-19	30	35	20	30	20	20	18-8	20	20
30	84	80	30	42	40	80	60	10	70

†Based on free cutting brass (C36000) = 100.

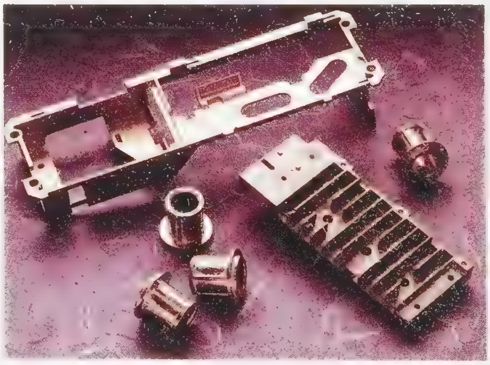
The Drive For Quality.

◆ THE DYNACAST COMPONENT ADVANTAGE: ◆

Quality

America's carmakers are committed to automotive excellence. They are determined to give their customers the quality they demand. To do that they must demand the same excellence from their suppliers. No wonder then that America's leading automakers use Dynacast components in the cars they build. Our high quality castings and moldings range from very simple to components that incorporate movable parts. Let us show you how cast and molded components from Dynacast will pack more quality into the products you manufacture. The Dynacast Component Advantage is quality you can use.

For a free presentation folder of Dynacast's component manufacturing capabilities, circle the Reader Service Number, or call 1-800-999-0009. In Canada call 1-800-344-7788.



DYNACAST

Zinc, aluminum and magnesium die castings, thermoplastics,
rigid and flexible bonded magnets—always with the Dynacast Advantage.

Plants: ◆ Yorktown Heights, NY; ◆ Spartanburg, SC; ◆ Seneca, SC; ◆ Marietta, OH; ◆ Schaumburg, IL;
◆ Tustin, CA; ◆ Montreal, CAN; ◆ Ontario, CAN; ◆ Arecibo, PR; ◆ Mexico

Circle 600

Magnesium

	TYPICAL ALLOY			
	AZ91D-F	AZ31B-F ZK60A-T5	AZ31B-F HM21A-T5 AZ80A-T5 ZK60A-T6	AXZ31B-H24 HK31A-H24 HM21A-T8
	FORM			
	Die casting	Extrusion	Forging	Sheet, plate
Density (lb/in.^{3})	0.065	0.064-0.066	0.065-0.066	0.064-0.065
Melting temperature (°F)	875-1,105	970-1,175	970-1,202	1,050-1,202
Coefficient of thermal expansion (10^{-6} in./in.-°F)	14.5	14.3-14.5	14.3-14.5	14.3-14.5
Thermal conductivity (Btu-ft/h-ft^2-°F)	31	44-70	—	44-79
Electrical resistivity (microhm-cm)	12.9	5.7-9.2	5.0-9.2	5.0-9.2
Yield strength (10^3 psi)	23	28-44	22-39	21-32
Tensile strength (10^3 psi)	34	38-53	34-50	33-42
Impact strength, Charpy (ft-lb)	2.0	3.2	3.2	—
Fatigue endurance limit (10^3 psi)	14	16-23	15-18	16-24
Creep strength, 0.1% in 100 h (10^3 psi)	3-4 (250°F)	Up to 5 (250°F)	5 (500°F)	Up to 8 (500°F)
Elongation in 2 in. (%)	3	11-15	6-11	9-21
Modulus of elasticity (10^6 psi)	6.5	6.5	6.5	6.5

treated to further improve properties.

Cast magnesium alloys are dimensionally stable to about 200°F. Some cast magnesium-aluminum-zinc alloys may undergo permanent growth if used above that temperature for long periods. Permanent-mold castings are as strong as sand castings, and they generally provide closer dimensional tolerances and better surface finish. Typical applications of magnesium gravity castings are aircraft engine components and wheels for race and sports cars.

Design of die-cast magnesium parts follows the same principles established for other die-casting metals. Maximum mechanical properties in a typical alloy are developed in wall thicknesses ranging from 0.078 to 0.150 in. Chain-saw and power-tool housings, archery-bow handles, and attache-case frames are typical die-cast applications.

Magnesium is easy to hot work, so fewer forging steps are usually required than for other metals. Bending, blocking, and finishing are usually the only operations needed. Typical magnesium forgings are missile fuselage connector rings.

Standard extruded shapes include round, square, rectangular, and hexagonal bars; angles, beams, and channels; and a variety of tubes. Luggage frames and support frames for military shelters are examples of magnesium extrusions.

Methods used for joining magnesium are gas tungsten-arc (TIG) and gas metal-arc (MIG) welding, spotwelding, riveting, and adhesive bonding. Mechanical fasteners can be used on magnesium, provided that stress concentrations are held to a safe minimum. Only ductile aluminum rivets should be used, preferably alloy 5056-H32, to minimize galvanic-corrosion failure at riveted joints.

Specification: Magnesium alloys are designated by a system established by the ASTM that covers both chemical compositions and tempers.

The first two letters of the designation identifies the two alloying elements specified in the greatest amount. The letters are arranged in order of decreasing percentages or alphabetically if the elements are present in equal amounts. The letters are followed by respective percentages rounded off to whole numbers, followed by a final serial letter. The serial letter indicates some variation in composition of minor alloying constituents or impurities.

The letters that designate the more common magnesium alloying elements are

A — Aluminum
E — Rare earths
H — Thorium
K — Zirconium
L — Lithium
M — Manganese
Q — Silver
S — Silicon
Z — Zinc

For example, magnesium alloy AZ31B contains 3% aluminum (code letter A) and 1% zinc (code letter Z).

Resisting corrosion: A problem with magnesium has been its lack of sufficient corrosion resistance for many applications, particularly in the alloys used for die and sand casting. The problem has been solved by the two major supplies, Dow and AMAX; both have developed corrosion-resistant, high-purity AZ91 alloys for die casting, and both also offer a sand-casting grade.

The die-casting grade is now designated by ASTM as AZ91D and will, for all practical purposes, replace AZ91B. The sand-casting grade received the designation AZ91E from ASTM. The high-purity alloys are said to be as much as 100 times more corrosion resistant than standard magnesium alloys, and more resistant to saltwater than die-cast 380 aluminum alloy or cold-rolled steel, tested according to ASTM B117. Research in magnesium metallurgy has shown that the ability of magnesium to resist corrosion in a service environment of salt-laden air or spray depends heavily on keeping contaminants (iron, nickel, copper) below their maximum tolerance limits during all production operations.

The high-purity magnesium die-casting alloy has already replaced other metals as well as a number of plastics in a variety of U.S. passenger-car and lightweight-truck components. Examples include valve and timing-gear covers, brackets, clutch and transfer-case housings, grille panels, headlamp doors, windshield-wiper motor housings, and various interior trim parts.

Nickel

Structural applications that require specific corrosion resistance or elevated temperature strength receive the necessary properties from nickel and its alloys. Some nickel alloys are among the toughest structural materials known. When compared to steel, other nickel alloys have ultrahigh strength, high proportional limits, and high moduli of elasticity. Commercially pure nickel has good electrical, magnetic, and magnetostrictive properties.

Common nickel alloy families include: commercially pure nickel; binary systems, such as Ni-Cu, Ni-Si, and Ni-Mo; ternary systems, such as Ni-Cr-Fe and Ni-Cr-Mo; more complex systems, such as Ni-Cr-Fe-Mo-Cu (with other possible additions); and superalloys. Nickel content throughout the alloy families ranges from 32.5 to 99.5%.

At cryogenic temperatures, nickel alloys are strong and ductile. Several nickel-base superalloys are specified for high-strength applications at temperatures to 2,000°F. High-carbon nickel-base casting alloys are commonly used at moderate stresses above 2,200°F.

Alloy characteristics: Commercial nickel and nickel alloys are available in a wide range of wrought and cast grades; however, considerably fewer casting grades are available. Wrought alloys tend to be better known by tradenames such as Monel, Hastelloy, Inconel, Incoloy, etc. Casting alloys are identified by Alloy Casting Institute and ASTM designations. Wrought and cast nickel alloys are often used together in systems built up from wrought and cast components. The casting alloys contain additional elements, such as silicon and manganese, to improve castability and pressure tightness.

Commercially pure nickels and extrahigh nickel alloys: Primary wrought materials in this group are Nickel 200 and 201, both of which contain 99.5% Ni. The cast grade, designated CZ-100, is recommended for use at temperatures above 600°F because its lower carbon content prevents graphitization and attendant ductility loss. Both wrought grades are particularly resistant to caustics, high-temperature halogens and hydrogen halides, and salts other than oxidizing halides. These alloys are particularly well suited for food-contact applications.

Duranickel 301, a precipitation-hardened, 94% nickel alloy, has excellent spring properties to 600°F. During thermal treatment, Ni_3AlTi particles precipitate throughout the matrix. This action enhances alloy strength. Corrosion resistance is similar to that of commercially pure wrought nickel.

Binary nickel alloys: The primary wrought alloys in this category are the Ni-Cu grades known as Monel alloy 400 (Ni-31.SCu) and K-500 (Ni-29.SCu), which also contain small amounts of Al, Fe, and Ti. The Ni-Cu alloys differ from Nickel 200 and 201 because their strength and hardness can be increased by age hardening. Although the Ni-Cu alloys share many of the corrosion characteristics of commercially pure nickel, their resistance to sulfuric and hydrofluoric acids and brine is better. Handling of waters, including seawater and brackish water, is a major application. Monel alloys 400 and K-500 are immune to chloride-ion stress-corrosion cracking, which is often considered in their selection.

Other commercially important binary nickel compositions are Ni-Mo and Ni-Si. One binary type, Hastelloy alloy B-2 (Ni-28Mo), offers superior resistance to hydrochloric acid, aluminum-chloride catalysts, and other strongly reducing chemicals. It also has excellent high-temperature strength in inert atmospheres and vacuum.

Cast nickel-copper alloys comprise a low and high silicon grade. M-35-1 and QQ-N-288, Grades A and E (1.5% Si), are commonly used in conjunction with wrought nickel-copper in pumps, valves, and fittings. A higher silicon grade, QQ-N-288, Grade B (3.5% Si), is used for rotating parts and wear rings because it combines corrosion resistance with high strength and wear resistance. Grade D (4.0% Si) offers exceptional galling resistance.

Two other binary cast alloys are ACI N-12M-1 and N-12M-2. These Ni-Mo alloys are commonly used for handling hydrochloric acid in all concentrations at temperatures up to the boiling point. These alloys are produced commercially under the tradenames Hastelloy alloy B and Chlorimet 2.

Ternary nickel alloys: Two primary wrought and cast compositions are Ni-Cr-Fe and Ni-Cr-Mo. Ni-Cr-Fe is known commercially as Haynes alloys 214 and 556, Inconel alloy 600, and Incoloy alloy 800. Haynes new alloy No. 214 (Ni-16Cr-2.5Fe-4.5Al-Y) has excellent resistance to oxidation to 2,200°F, and resists carburizing and chlorine-contaminated atmospheres. Haynes patented alloy No. 556 (Fe-20Ni-22Cr-18Co) combines effective resistance to sulfidizing, carburizing, and chlorine-bearing environments with good oxidation resistance, fabricability and high-temperature strength. Inconel alloy 600 (Ni-15.5Cr-8Fe) has good resistance to oxidizing and reducing environments. Intended for severely corrosive conditions at elevated temperatures, Incoloy 800 (Ni-46Fe-21Cr) has good resistance to oxidation and carburization at elevated temperatures, and it resists sulfur attack, internal oxidation, scaling, and corrosion in many atmospheres.

A cast Ni-Cr-Fe alloy CY-40, known as Inconel, has higher carbon, Mn, and Si contents than the corresponding wrought grade. In the as-cast condition, the alloy is insensitive to the type of intergranular attack encountered in as-cast or sensitized stainless steels.

Significant additions of molybdenum make Ni-Cr-Mo alloys highly resistant to pitting. They retain high strength and oxidation resistance at elevated temperatures, but they are used in the chemical industry primarily for their resistance to a wide variety of aqueous corrosives. In many applications, these alloys are considered the only materials capable of withstanding the severe corrosion conditions encountered.

In this group, the primary commercial materials are C-276, Hastelloy alloy C-22, and Inconel alloy 625. Hastelloy alloy C-22 (Ni-22Cr-13Mo-3W-3Fe) has better overall corrosion resistance and versatility than any other Ni-Cr-Mo alloy. Alloy C-276 (57Ni-15.5Cr-16Mo) has excellent resistance to strong oxidizing and reducing corrosives, acids, and chlorine-contaminated hydrocarbons. Alloy C-276 is also one of the few materials that withstands the corrosive effects of wet chlorine gas, hypochlorite, and chlorine dioxide. Hastelloy alloy C-22, the newest alloy in this group, has outstanding resistance to pitting, crevice corrosion, and stress-corrosion cracking. Present applications include the pulp and paper industry, various pickling acid processes, and production of pesticides and various agrichemicals.

Two grades of cast Ni-Cr-Mo alloys, ACI CW-12M-1 and CW-12M-2, are used in severe corrosion service, often involving combinations of acids at elevated temperatures. The two versions of CW-12M are also produced as Hastelloy C and Chlorimet.

Complex alloys: Ni-Cr-Fe-Mo-Cu is the basic composition in this category of nickel alloys. They offer good resistance to pitting, intergranular corrosion, chloride-ion stress-corrosion cracking, and general corrosion in a wide range of oxidizing and reducing environments. These alloys are frequently used in applications involving sulfuric and phosphoric acids.

Important commercial grades include Hastelloy alloys G-30 and H, Haynes alloy No. 230, Inconel alloys 617, 625, and 718, and Incoloy alloy 825.

Haynes alloy No. 230 (Ni-22Cr-14W-2Mo) has excellent high-temperature strength, oxidation resistance, and thermal stability, making it suitable for various applications in the aerospace, airframe, nuclear, and chemical-process industries.

Hastelloy alloy G-30 (Ni-30Cr-6Mo-2.5W-15Fe) has many advantages over other metallic and nonmetallic materials in handling phosphoric acid, sulfuric acid, and oxidizing acid mixtures.

Hastelloy alloy H (Ni-22Cr-9Mo-2W-18Fe) is a patented alloy with localized corrosion resistance equivalent or better to alloy 625. Alloy H also has good resistance to hot acids and excellent resistance to stress-corrosion cracking. It is often used in flue gas desulfurization equipment.

Inconel alloy 617 (Ni-22Cr-12.5Co-9Mo-1.5Fe-1.2Al) resists cyclic oxidation at 2,000°F, and has good stress-rupture properties above 1,800°F.

Inconel alloy 625 (Ni-21.5Cr-2.5Fe-9Mo-3.6Nb+Ta) has high strength and toughness from cryogenic temperatures to 1,800°F, good oxidation resistance, exceptional fatigue strength, and good resistance to many corrosives. Furnace mufflers, electronic parts, chemical and food-processing equipment, and heat-treating equipment are among a few of the many applications for alloy 615.

Inconel alloy 718 (Ni-18.5Fe-19Cr-3Mo-5Nb+Ta) has excellent strength from −423 to 1,300°F. The alloy is age hardenable, can be welded in the fully aged condition, and has excellent oxidation resistance up to 1,800°F.

Incoloy 825 (42Ni-30Fe-21.5Cr-3Mo-2.25Cu) offers excellent resistance to a wide variety of corrosives. It resists pitting and intergranular corrosion, reducing acids, and oxidizing chemicals. Applications include pickling-tank heaters and hooks, spent nuclear-fuel-element recovery, chemical-tank trailers, evaporators, food-processing equipment, sour-well tubing, hydrofluoric-acid production, pollution-control equipment, and radioactive-waste systems.

Superalloys: One class of Ni-based superalloys is strengthened by intermetallic compound precipitation in a face-centered cubic matrix. The strengthening precipitate is gamma prime, typified by Waspaloy (Ni-19.5Cr-13.5Co-4.3Mo-3.0Ti-1.4Al-2.0Fe), Udimet 700 (Ni-15Cr-18.5Co-5Mo-3.4Ti-4.3Al-<1Fe), and the modern but complex Rene 95 (Ni-14Cr-8Co-3.5Mo-3.5W-3.5Nb-2.5Ti-3.5Al).

Another type of Ni-based superalloy is represented by Hastelloy alloy X (Ni-22Fe-9Mo-22Cr-1.5Co). This alloy is essentially solid-solution strengthened, but probably also derives some strengthening from carbide precipitation through a working-plus-aging schedule.

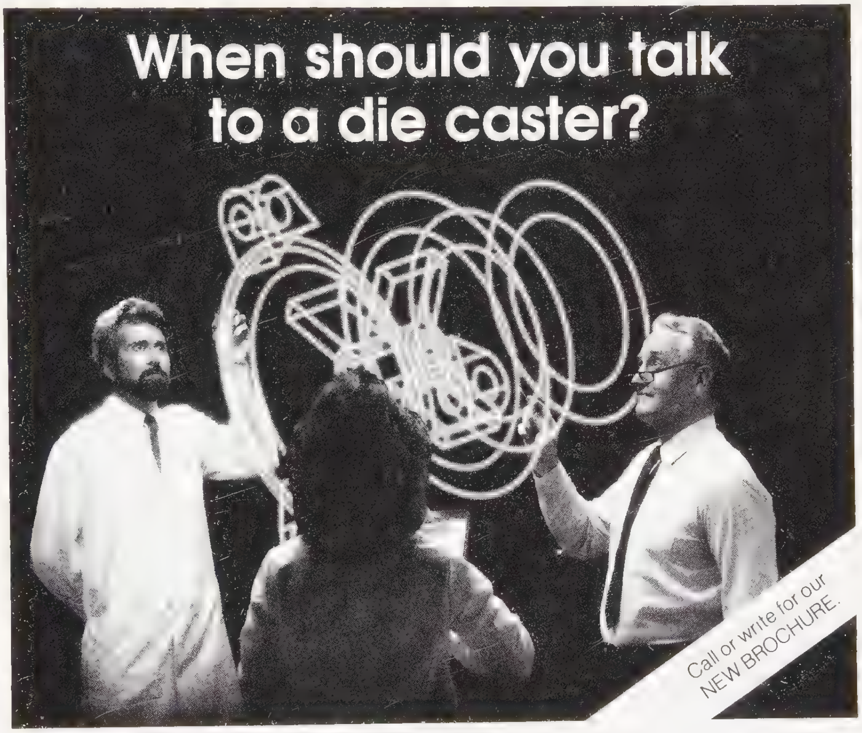
A third class includes oxide-dispersion-strengthened (ODS) alloys such as IN MA-754 (Ni-20Cr-0.6yttria) and IN MA-6000 (Ni-15Cr-2Mo-4W-2.5Ti-4.5Al), which are strengthened by dispersions such as yttria coupled (in some cases) with gamma prime precipitation (MA-6000).

Nickel-based superalloys are used in cast and wrought forms, although special processing (powder metallurgy/isothermal forging) often is used to produce wrought versions of the more highly alloyed compositions (U-700, Astroloy, IN-100).

An additional dimension of Ni-based superalloys has been the introduction of grain-aspect ratio and orientation as a means of controlling properties. In some instances, grain boundaries have been removed. Wrought powder-metallurgy alloys of the ODS class and cast alloys such as MAR M-247 have demonstrated property improvements due to grain morphology control by directional crystallization or solidification. Virtually all uses of the cast and wrought nickel-base superalloys are for gas-turbine components.

Fabrication: Most wrought-nickel alloys can be hot and cold worked, machined, and welded successfully. The casting alloys can be machined or ground, and many can be welded and brazed.

Nearly any shape that can be forged in steel can also be forged in nickel and nickel alloys. However, because nickel work hardens easily, severe cold-forming operations require frequent intermediate annealing to restore soft temper. Annealed cold-rolled sheet, not stretcher leveled, is best for spinning and other manual work. In general, cold-drawn rods machine much more cleanly and readily than hot-rolled or


When should you talk to a die caster?
Call or write for our NEW BROCHURE.

Gibbs engineers apply die casting expertise to your design to eliminate secondary operations, hold closer tolerances, reduce weight and minimize scrap.

With Gibbs Die Casting Aluminum, it's simple – Before you start your design.

Gibbs' staff of design engineers can help you eliminate secondary operations...hold closer tolerances...reduce weight...even minimize scrap by applying die casting expertise to design ideas.

But to get benefits like these, you need to involve us early in the design process. We'll work with you and your designs, just as we do every day for customers in the automotive, appliance and other OEM industries.

So before you start designing your next project, remember the Gibbs engineers. We can help you make better parts...by design.

Gibbs Die Casting Aluminum Corp.
369 Community Drive, Henderson, KY 42420
Phone: (502) 827-1801 FAX: (502) 827-7840

Circle 601

annealed material.

Nickel alloys can be joined by shielded metal-arc, gas tungsten-arc, gas metal-arc, plasma-arc, electron-beam, oxyacetylene, and resistance welding; silver and bronze brazing; and soft soldering. Resistance welding methods include spot, seam, projection, and flash welding.

Special nickel alloys, including superalloys, are best worked at about 1,800 to 2,200°F. In the annealed condition, these alloys can be cold worked by all standard methods. Required forces and rate of work hardening are intermediate between those of mild steel and Type 304 stainless steel. These alloys work harden to a greater extent than the austenitic stainless steels, so they require more intermediate annealing steps.

Both cold-worked and hot-worked Ni-Cu require thermal treatment to develop optimum ductility and to minimize distortion during subsequent machining. Stress relieving before machining is recommended to minimize distortion after metal removal. Stress equalizing of cold-worked Cu-Ni increases yield strength without marked effects on other properties.

Many Hastelloy alloys can be upset forged if the length of the piece is no greater than twice its diameter. However, upsetting should never be attempted on a cast ingot. Cast ingots must be reduced at least 75% before hot upsetting.

Most wrought nickel-based alloys can be formed from sheet into complex shapes involving considerable plastic flow. These alloys are processed in the annealed condition.

Precious metals

Precious metals may seem unlikely as engineering materials, but the same expensive metals used for coinage and jewelry also satisfy applications requiring the ultimate in corrosion resistance or electrical conductivity. Three subgroups make up the entire family of precious metals: silver and silver alloys; gold and gold alloys; and the platinum metals, which are platinum, palladium, rhodium, ruthenium, iridium, and osmium. The six platinum metals are so grouped because they occur naturally in the same ore.

Most precious metals are available as sheet, tape, foil, wire, tubing, gauze, discs, electrodes, cathodes, crucibles, catalysts, and salts or solutions for plating and coating. All precious metals are nearly completely corrosion resistant; platinum metals withstand service up to 3,200°F without any evidence of erosion or corrosion.

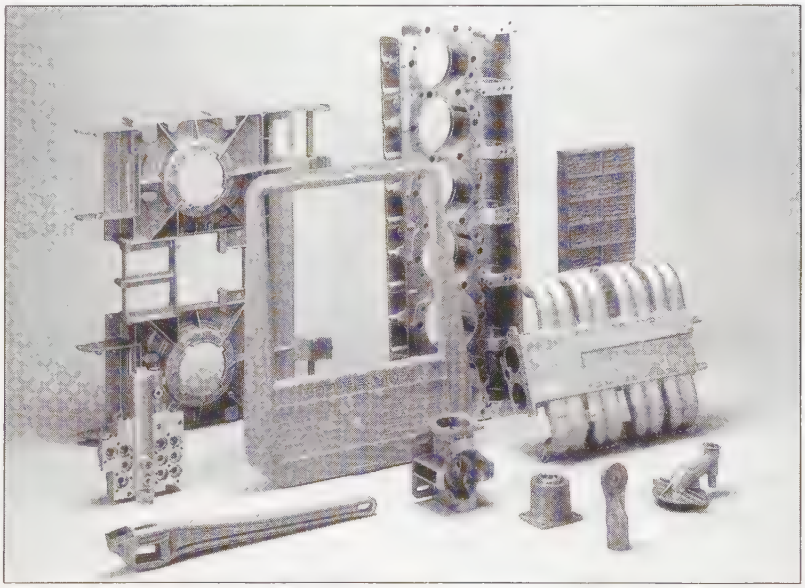
Gold: An extremely soft, ductile metal, gold undergoes very little work hardening. A gram of pure gold can be worked into leaf covering 6 ft^2 and only 0.0000033 in. thick. Because pure gold is too soft for large, freestanding components, it is used chiefly for linings or electrodeposits and is often alloyed with other metals such as copper or nickel to increase strength or hardness.

Gold is extremely inert. It is not attacked by nitric, hydrochloric, or sulfuric acid, but is dissolved by aqua regia and is attacked by sodium and potassium cyanide plus oxygen.

Silver: The least costly of the precious-metal group, silver is also very malleable, ductile, and corrosion resistant. Because it is not attacked by alkaline solutions, it is used to contain caustic soda and potash in all concentrations. Silver has the highest thermal and electrical conductivity of all metals.

Alloyed with copper, and sometimes with zinc, silver is used in high-melting temperature solders. These silver solders are used where more than ordinary

NEED ALUMINUM CASTINGS?



Stahl is your single source supplier.

At Stahl, we produce thousands of aluminum castings for hundreds of customers every day. As a matter of fact, we're the leading permanent mold aluminum foundry in the country. That's good news for you. Because, with that kind of experience, you won't have to worry about a thing when you work with us. We'll provide everything it takes to move your casting from the idea stage to a finished machined product as quickly and efficiently as possible. From CAD/CAM engineering to an in-house toolroom to a complete metallurgical lab. Give us a call at **1-800-821-7852** before your next casting job. And find out how our leading edge technology can work for you.

Stahl
Specialty Company
Kingsville, Missouri U.S.A. 64061
(816) 597-3322 • **(800) 821-7852** • FAX: (816) 597-3485

Circle 602

	Gold		Iridium	Osmium	Palladium	Platinum		Rhodium	Ruthenium	Silver	
	Annealed	Cold rolled 50%	Annealed		Annealed	Annealed	Cold rolled 50%	Annealed	Annealed	Annealed	Cold rolled 50%
Density (lb/in.^{3})	0.698		0.813	0.820	0.434	0.775		0.447	0.441	0.379	
Yield strength (10^3 psi)	—	30	—	—	5	2-5.5	27	—	—	8	44
Tensile strength (10^3 psi)	19	32	80	—	20-28	18-27	28-32	73	55	22	54
Elongation in 2 in. (%)	45	4	—	8	24-40	30-40	2.5-3.5	—	—	48	2.5
Modulus of elasticity (10^6 psi)	12	—	75	81	18	25	—	47	60	11	—
Melting temperature (°F)	1,948		4,437	5,533	2,829	3,222		3,565	4,197	1,763	
Coefficient of thermal expansion (10^{-6} in./in.-°F)	7.9		3.8	3.4	6.5	5.1		4.4	5.1	10.9	
Electrical resistivity (microhm-cm)	2.19		5.3	9.5	10.0	9.83		4.51	7.6	1.47	
Thermal conductivity (Btu-ft/hr-ft^2-°F)	172		34	—	41	42		50	—	242	

joint strength — or sometimes, electric conductivity — is required.

Platinum: A silver-white metal, platinum is extremely malleable, ductile, and corrosion resistant. When heated to redness, it softens and is easily worked. It is nearly nonoxidizable and is soluble only in liquids that generate free chlorine such as aqua regia. Because platinum is inert and stable, even at high temperatures, the metal is used for high-temperature handling of high-purity chemicals and laboratory materials. Other applications include electrical contacts, resistance wire, thermocouples, and standard weights. In gauze form, platinum is used as a catalyst in air-pollution control systems.

Palladium, iridium, and rhodium: These metals resemble and behave like platinum. All can be worked but, because they work harden, require annealing between forming operations. Rhodium and iridium are more brittle than palladium, however, and must be forged or swaged above 1,472°F. Iridium cannot be cold rolled at all.

Palladium, which is harder and lighter than platinum, is used as an electrically conductive coating. It is easily applied to printed-circuit boards and various types of contacts. Palladium is often alloyed with silver or copper.

Iridium has the best corrosion resistance of all metals. Because of its excellent resistance to attack by leaded fuels, iridium is used for spark-plug electrodes in aircraft engines and in similar applications where extreme reliability is required. It is also used as an alloying agent for increasing the corrosion resistance and hardness of platinum. Iridium-tungsten alloys are used for springs operating at temperatures as high as 800°C.

Rhodium has the highest electrical and thermal conductivity of the platinum-metals group and is the hardest. It has high reflectivity, which makes it ideal for mirrors and reflectors in high-temperature or highly corrosive applications. It is also used with platinum in thermocouple wire.

Ruthenium and osmium: Although they worked successfully and have no structural applications, these metals are used as alloying elements to increase hardness and electrical resistivity of platinum or other metals in this group. Typical applications for these alloys include electrical contacts and wire for electronic products.

Refractory metals

Refractory metals are characterized by their extremely high melting points, which range well above those of iron, cobalt, and nickel. They are used in demanding applications requiring high-temperature strength and corrosion resistance. The most extensively used of these metals are tungsten, tantalum, molybdenum, and columbium (niobium). They are mutually soluble and form solid-solution alloys with each other in any proportion. These four refractory metals and their alloys are available in mill forms as well as products such as screws, bolts, studs, and tubing.

Although the melting points of these metals are all well above 4,000°F, they oxidize at much lower temperatures. Accelerated oxidation in air occurs at 190°C for tungsten, 395°C for molybdenum, and 425°C for tantalum and columbium. Therefore, protective coatings must be applied to these metals if they are to be used at higher temperatures. Tensile and yield strengths of the refractory metals are substantially retained at high temperature.

Columbium and tantalum: These metals are usually considered together because most of their working characteristics are similar. They can be fabricated by most conventional methods at room temperature. Heavy sections for forging can be heated, without protection, to approximately 425°C.

Out of several commercial-grade tantalum alloys, those containing tungsten, columbium, and molybdenum generally retain the corrosion resistance of tantalum and provide higher mechanical properties. Columbium is also available in alloys containing tantalum, tungsten, molybdenum, vanadium, hafnium, zirconium, or carbon. Alloys provide improved tensile, yield, and creep properties, particularly in the 1,100 to 1,650°C range.

Most sheet-metal fabrication of columbium and tantalum is done in the thickness range of 0.004 to 0.060 in. Columbium, like tantalum, can be welded to itself and to certain other metals by resistance welding, tungsten inert-gas (TIG) welding, and to itself by inert-gas arc welding. Electron-beam welding can also be used, particularly for joining to other metals. However, surfaces that are heated above 315°C during welding must be protected with an inert gas to prevent embrittlement.

Principal applications for tantalum are in capacitor anodes, filaments, gettering devices, chemical-process equipment, and high-temperature aerospace engine components. Columbium is used in superconducting materials, thin-film substrates, electrical contacts, heat sinks, and as an alloying addition in steels and superalloys.

Molybdenum: Probably the most versatile of the refractory metals, molybdenum is also a natural resource of the United States. It is an excellent structural material for applications requiring high strength and rigidity at temperatures to 3,000°F where it can operate in vacuum or under inert or reducing atmospheres.

Unalloyed molybdenum and its principal alloy, TZM, are produced by powder-metallurgy methods and by vacuum-arc melting. Both are commercially available in ordinary mill product forms: forging billets, bars, rods, wire, seamless tubing, plate, strip, and thin foil. Compared to unalloyed molybdenum, the TZM alloy (Mo-0.5%Ti-0.1%Zr) develops higher strength at room temperature and much higher stress-rupture and creep properties at all elevated temperatures. At 1,800 to 2,000°F, TZM can sustain a 30,000-psi stress for over 100 h, three times that for unalloyed molybdenum.

Molybdenum and TZM are readily machined with conventional tools. Sheet can be processed by punching, stamping, spinning, and deep drawing. Some parts can be forged to shape. Molybdenum wire and powder can be flame sprayed onto steel substrates to salvage worn parts or to produce long-wearing, low-friction surfaces for tools.

In nonoxidizing environments, the metal resists attack by hydrochloric, hydrofluoric, sulfuric, and phosphoric acids. Molybdenum oxidizes at high temperatures to produce volatile, nontoxic, molybdenum trioxide; however, parts such as gimbled nozzles have been used successfully in rocket and missile-guidance systems when exposure time to the very-high temperatures of ballistic gases was brief.

Refractory metals

	Columbium	Molybdenum	Tantalum	Tungsten
Density (lb/in.^{3})	0.310	0.369	0.600	0.697
Melting temperature (°F)	4,474	4,730	5,425	6,170
Coefficient of thermal expansion (10^{-6} in./in.-°F)	3.8	2.8	3.6	2.5
Thermal conductivity (Btu-ft/hr-ft^2-°F)	31.5	84.5	31.5	96.6
Electrical conductivity (% IACS)	13.2	34.0	13.9	31.0
Electrical resistivity (microhm-cm)	12	5.7	13.5	5.5
Yield strength (10^3 psi)				
At 70°F	20	82	35	220
At 1,800°F	5	30*	10	15*
Tensile strength (10^3 psi)				
At 70° F	30-60	120-200	35-70	100-500
At 1,700°F	17	50*	27	66*
Elongation in 2 in. (%)	25	10	35	3
Modulus of elasticity (10^6 psi)				
At 70°F	15	47	27	59

*At 1,600°F.

Molybdenum parts can be welded by inertia, resistance, and spot methods in air; by TIG and MIG welding under inert atmospheres; and by electron-beam welding in vacuum. The best welds are produced by inertia (friction) welding and electron-beam welding; welds produced by the other techniques are less ductile. Generally, arc-cast metal develops better welds than do powder-metallurgy products. Heavy sections of molybdenum should be preheated and postheated when they are welded to reduce thermal stresses.

Because molybdenum has a modulus of elasticity of 47 × 10^6 psi at room temperature, it is used for boring bars and the quills for high-speed internal grinders to avoid vibration and chatter. Its relatively high electrical conductivity makes unalloyed molybdenum useful for electrical and electronic applications. It is used in the manufacture of incandescent lamps, as substrates in solid-state electronic devices, as electrodes for EDM equipment and for melting glass, and as heating elements and reflectors or radiation shields for high-temperature vacuum furnaces.

Because it retains usable strength at elevated temperatures, has a low coefficient of thermal expansion, and resists erosion by molten metals, the TZM alloy is used for cores in die casting of aluminum, and for die cavities in casting of brass, bronze, and even stainless steel. Dies of the TZM alloy weighing several thousand pounds are used for isothermal forging of superalloy components for aircraft gas turbines, and die inserts made of TZM have been used for extruding steel shapes. Piercer points of TZM are used to produce stainless-steel seamless tubing.

Tungsten: In many respects, tungsten is similar to molybdenum. The two metals have about the same electrical conductivity and resistivity, coefficient of thermal expansion, and about the same resistance to corrosion by mineral acids. Both have high strength at temperatures above 2,000°F, but because the melting point of tungsten is higher, it retains significant strength at higher temperatures than molybdenum does. The elastic modulus for tungsten is about 25% higher than that of molybdenum, and its density is almost twice that of molybdenum. All commercial unalloyed tungsten is produced by powder-metallurgy methods; it is available as rod, wire, plate, sheet, and some forged shapes. For some special applications, vacuum-arc-melted tungsten can be produced, but it is expensive and limited to relatively small sections.

Several tungsten alloys are produced by liquid-phase sintering of compacts of tungsten powder with binders of nickel-copper, iron-nickel, iron-copper, or nickel-cobalt-molybdenum combinations; tungsten usually comprises 85 to 95% of the alloy by weight. These alloys are often identified as heavy metals or machinable tungsten alloys. In compact forms, the alloys can be machined by turning, drilling, boring, milling, and shaping; they are not available in mill product forms because they are unable to be wrought at any temperature.

The heavy-metal alloys are especially useful for aircraft counterbalances and as weights in gyratory compasses. Heavy-metal inserts are used as the cores of high-mass military projectiles. Tungsten alloys are widely used for counterbalances in sports equipment such as golf clubs and tennis racquets. X-ray shielding is another important application of the tungsten alloys.

Filaments for incandescent lamps are usually coils of very fine unalloyed tungsten wire. Electronic tubes are often constructed with tungsten as the heaters; some advanced tubes use heaters made from a tungsten alloy containing 3% rhenium. A thermocouple rated to 4,350°F consists of one tungsten wire alloyed with 25% rhenium and another wire alloyed with 5% rhenium.

Nozzle throats of forged and machined unalloyed tungsten have been used in solid-fuel rocket engines; at one time, throats were machined from porous consolidations of tungsten powder that were infiltrated with silver for exposure to gases at temperatures near 3,500°C. Unalloyed tungsten is used for X-ray targets, for filaments in vacuum-metallizing furnaces, and for electrical contacts such as the distributor points in automotive ignition systems. Tungsten electrodes form the basis for TIG welding. Water-cooled tungsten tips are used for nonconsumable electrode vacuum-arc melting of alloys.

Cutting tools and parts that must resist severe abrasion are often made of tungsten carbide. Tungsten-carbide chips or inserts, with the cutting edges ground, are attached to the bodies of steel tools by brazing or by screws. The higher cutting speeds and longer tool life made feasible by the use of tungsten-carbide tools are such that the inserts are discarded after one use. Tungsten-carbide dies have been used for many years for drawing wire. Inserts of tungsten carbide are used in rotary bits for drilling oil and gas wells and in mining operations. Fused tungsten carbide

Small Zinc Die Cast Components

FISHERCAST®
DIVISION OF FISHER GAUGE LIMITED

Box 179, Peterborough, Ontario, Canada K9J 6Y9
Phone (705) 748-9522 Facsimile: (705) 745-8818
Plants: Watertown, N.Y. and Peterborough, Canada

Circle 603

At Fishercast, quality means:

☐ Mirror finish (4-8 microinches)
☐ Center bore parallel within .0005″
☐ Concentricities within .002″ T.I.R.
☐ Flash free, ready for assembly
☐ Consistent quality regardless of volume

At Fishercast we pride ourselves in manufacturing the finest zinc die castings in the world today, with consistent quality through long production runs—even with the most difficult configurations. A challenging claim! Try us, and see!

FISHERCAST
DIVISION OF FISHER GAUGE LIMITED

Box 179, Peterborough, Ontario, Canada K9J 6Y9
Phone (705) 748-9522 Facsimile: (705) 745-8818
Plants: Watertown, N.Y. and Peterborough, Canada

We're specialists

☐ High production rates
☐ Unique casting technology
☐ State-of-the-art equipment

In one way or another, all of our Company's activities center around die casting technology. For over 50 years we have continually developed our specialized knowledge and skills in this area.

The Fishercast Division produces several hundred million zinc die castings annually—a figure which is dramatically increasing every year.

Developed by the Fishertech Division, our die casting equipment is state-of-the-art. Along with our total zinc component casting technology, this gives us a particular advantage over competitors. We cast configurations others consider difficult or impossible. We maintain close tolerances over long production runs. And we produce an end product which is flash free, ready for immediate assembly.

Circle 603

Fishercast® can solve your small component design problems with our automatic, high speed, small zinc alloy die casting process. Components with complex configurations are cast flash-free from minuscule proportions up to 32 ounces in weight. Costly secondary operations such as trimming and deburring are totally eliminated.

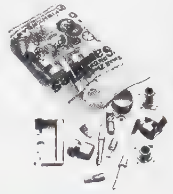
High volume, custom components are die cast to tolerances as close as .0005," thin wall sections to .015" and surface finishes as smooth as 4 to 8 microinches.

Versatility, wear resistance, strength and durability are some of the outstanding characteristics of zinc alloy. This die casting process can provide savings of up to 50% over alternate methods and materials – without compromising component integrity or performance.

Fishercast zinc alloy die cast components can be found in hundreds of applications including automotive vehicles, industrial controls, appliances, electronic components, power tools, hardware and many more.

As a quality supplier, our abilities as a problem solver have made us a recognized world leader in the technology of small component zinc alloy die casting.

Reach out to Fishercast and our unique capabilities will be at your fingertips. Call Fishercast today.



Send for a free bag of samples

FISHERCAST®
DIVISION OF FISHER GAUGE LIMITED
Box 179, Peterborough, Ontario, Canada K9J 6Y9
Phone (705) 748-9522 Facsimile: (705) 745-8818
Plants: Watertown, N.Y., and Peterborough, Canada

SOLUTIONS TO COMPLEX DESIGN PROBLEMS AT YOUR FINGERTIPS

©Copyright 1991 Fisher Gauge Limited 80-6-12 is applied to the surfaces of mining machinery that is subjected to severe wear.

Tin

Tin is characterized by a low-melting point (450°F), fluidity when molten, readiness to form alloys with other metals, relative softness, and good formability. The metal is nontoxic, solderable, and has a high boiling point. The temperature range between melting and boiling points exceeds that for nearly all other metals (which facilitates casting). Upon severe deformation, tin and tin-rich alloys work soften.

Principal uses for tin are as a constituent of solder and as a coating for steel (tinplate, or terneplate). Tin is also used in bronze, pewter, and bearing alloys. Tin and tin alloys can be cast, rolled, extruded, or atomized. Because pure tin is too weak to be used alone for most mechanical applications, it is usually alloyed with elements such as copper, antimony, lead, bismuth, and zinc.

Tin and its alloys are cast using most conventional techniques, including gravity die casting, pressure die casting, and centrifugal casting. Tin-alloy castings are sound and dimensionally accurate because little shrinkage occurs on solidification. Essential to the casting of tin-rich alloys is the need to reduce microstructure segregation, which occurs during solidification. Part and mold designs should be such that ample metal is fed to remote regions of the mold cavity. Because of their low-melting points, tin-rich alloys can be cast in carbon-steel or rubber molds.

Pewter: Alloys contain from 1 to 8% antimony and 0.5 to 3% copper, and have excellent castability and workability. For spun pewter products, antimony content is usually below 7%, and pewter casting alloys contain 7.5% antimony and 0.5% copper. Because of the excellent drawing and spinning properties of tin, wrought parts are usually made from pewter that is first cast into slabs, then rolled into sheet.

Bearing alloys: These low-friction materials may contain high percentages of antimony (to 10%), copper (to 10%), or aluminum (to 80%). They include babbitt metal, bronze, and aluminum-tin. Although soft, conformable, and corrosion resistant, their low mechanical strength must be boosted by bonding to steel, cast iron, or bronze backing materials.

Die-casting tin-based alloys: Historically, these were the first materials to be die cast. Low melting point and extreme fluidity of these alloys produce sound, intricate castings inexpensively and with little wear on molds. Antimony, copper, and lead are the principal additions to tin in die-casting alloys. These alloys are mainly gravity or centrifugally die cast. Cast tin-alloy parts can be held to tolerances of 0.0005 in./in., with wall thicknesses down to 1/32 in. Shrinkage is negligible.

Fusible tin alloys: Melting temperatures for these alloys are usually below the solidus of eutectic-base tin-lead solders (361°F). Primary alloying elements include bismuth, lead, cadmium, and indium. Most of these alloys provide electrical or mechanical links in safety devices. Other applications include low-temperature solders, seals for glass and other heat-sensitive materials, foundry patterns, molds for low-volume production of plastic parts, internal support for tube bending, and localized thermal treatment of parts.

Tin and tin-alloy powders: Produced by atomization techniques, these powders are available in a number of mesh sizes. They are used in the manufacture of powder-metallurgy parts, in tinning and solder pastes, and in the spray metallization of surfaces.

In small amounts, tin is also combined with titanium, zirconium, and other metals to provide special properties. It is used as an alloy in nodular and gray irons to provide greater strength, increased and uniform hardness, and improved machinability. Tin-nickel and tin-zinc coatings are used in the braking systems of automobiles. The tin-nickel alloy is coated on disc-brake pistons because of its good resistance to wear and corrosion. Tin-zinc is used to plate master cylinders in automotive braking systems.

Noncritical parts such as costume jewelry and small decorative items such as figurines can be made by casting pewter and other low-melting tin-

Tin-based babbitt alloys (Data from ASTM B-23)

	COMPOSITION (weight %)		
	91 Sn-4.5Sb-4.5Cu	89Sn-7.5Sb-3.5Cu	84Sn-8Sb-8Cu
Melting range (°F)	443-700	466-669	464-792
Density (lb/in.^{3})	0.265	0.267	0.269
Hardness, Brinell[a]			
At 68°F	17.0	24.5	27.0
At 212°F	8.0	12.0	14.5
Ultimate compressive strength[b] (psi)			
At 68°F	12,850	14,900	17,600
At 212°F	6,950	8,700	9,900
Johnson's apparent elastic limit[c] (psi)			
At 68°F	2,450	3,350	5,350
At 212°F	1,050	1,100	1,300
Yield point[d] (psi)			
At 68°F	4,400	6,100	6,600
At 212°F	2,650	3,000	3,150

[a] 10-mm ball, 500 kg load, 30 s

[b] Ultimate strength values were taken as the unit load necessary to produce a deformation of 25% of the length of the specimen. (The test specimens were cylinders 1.5 in. long × 0.5 in. in diameter, machined from chill castings.)

[c] Johnson's apparent elastic limit is the unit stress at the point where the slope of the tangent to the curve is two-thirds of its slope at the origin.

[d] Values for yield point were taken from stress-strain curves at a deformation of 0.125% of gage length.

Selected tin-based alloys

	Straits tin	60/40 solder	Tin-antimony solder	Tin-silver solder	Modern pewter
Composition (weight %)	99.8Sn	60Sn-40Pb	95Sn-5Sb	96.5Sn-3.5Ag	91Sn-7Sb-2Cu
Density (lb/in^3)	0.264	0.312	0.260	0.375	0.263
Melting temperature (°F)	450	361-370	452-464	430	471-563
Tensile strength (10^3 psi)	2.1	5.6	5.5	6.5	7.6[a]
Shear strength (10^3 psi)	1.80	4.8	5.8	4.6	—
Impact strength, Charpy V-notch (ft-lb)	34.5	24	42	40.0[b]	—
Modulus of elasticity (10^6 psi)	7.3	4.4	7.2	—	7.7
Coefficient of thermal expansion (10^{-6} in./in.-°F)	12.8[c]	13.3	15.0	—	—
Electrical resistivity (microhm-cm)	11.0[d]	15	14.5	12.31	—

[a] Cold-rolled sheet, 32% reduciton. [b] Estimated. [c] At 122°F [d] At 32°F

Mechanical properties of tin-based alloys vary over a wide range, depending on testing rate.

based alloys in rubber molds. Tin die-casting alloys are suitable for low-strength precision parts and bearings for household appliances, engines, motors and generators, and gas turbines. These bearings perform well even at start-up and run-down periods of operation, at which times they carry a heavy, unidirectional load without the benefit of a fully formed hydrodynamic film. Other applications for tin-based die castings include parts for food-handling equipment, instruments, gas meters, and speedometers.

Titanium

Depending on the predominant phase or phases in their microstructure, titanium alloys are categorized as alpha, alpha-beta, and beta. This natural grouping not only reflects basic titanium production metallurgy, but it also indicates general properties peculiar to each type.

Titanium alloys

Nominal alloy composition	Alloy type	Yield strength (10 psi)			
			Typical		
		Min at RT	600°F	800°F	1,000°F
***Ti** (high purity)	Alpha	25	15	13	—
***Ti** (plus O_2, Fe)	Alpha	70	24	21	16
Ti-0.2Pd	Alpha	40	18	15	11
Ti-5Al-2.5Sn	Alpha	115	65	59	55
Ti-6Al-2Sn-4Zr-2Mo	Alpha	120	75	70	60
Ti-6Al-4V	Alpha-beta	120	90	75	60
†Ti-6Al-4VEL1	Alpha-beta	120	—	—	16.5
Ti-3Al-SV-6Cr-4Zr-4Mo	Beta	160	140	125	110

*Also available with 0.05% max Fe for superior corrosion resistance.

†Develops excellent fracture toughness properties with special mill processing.

The alpha phase in pure titanium is characterized by a hexagonal close-packed crystalline structure that remains stable from room temperature to approximately 1,620°F. The beta phase in pure titanium has a body-centered cubic structure, and is stable from approximately 1,620°F to the melting point of about 3,040°F.

Adding alloying elements to titanium provides a wide range of physical and mechanical properties. Certain alloying additions, notably aluminum, tend to stabilize the alpha phase; that is, they raise the temperature at which the alloy will be transformed completely to the beta phase. This temperature is known as the beta-transus temperature.

Alloying additions such as chromium, columbium, copper, iron, manganese, molybdenum, tantalum, and vanadium stabilize the beta phase by lowering the temperature of transformation from alpha to beta. Some elements, notably tin and zirconium, behave as neutral solutes in titanium and have little effect on the transformation temperature, acting instead as strengtheners of the alpha phase.

Alpha alloys: The single-phase and near-single-phase alpha alloys of titanium have good weldability. The generally high aluminum content of this group of alloys ensures good strength characteristics and oxidation resistance at elevated temperatures (in the range of 600 to 1,100°F). Alpha alloys cannot be heat treated to develop higher mechanical properties because they are single-phase alloys.

Alpha-beta alloys: The addition of controlled amounts of beta-stabilizing alloying elements causes the beta phase to persist below the beta transus temperature, down to room temperature, resulting in a two-phase system. These two-phase titanium alloys can be strengthened significantly by heat treatment consisting of a quench from some temperature in the alpha-beta range, followed by an aging cycle at a somewhat lower temperature. Beta-phase transformation, which would normally occur on slow cooling, is suppressed by the quenching. The aging cycle causes the precipitation of some fine alpha particles from the metastable beta, imparting a structure that is stronger than the annealed alpha-beta structure. Although heat-treated alpha-beta alloys are stronger than the alpha alloys, their ductility is proportionally lower.

Beta alloys: The high percentage of beta-stabilizing elements in these alloys results in a microstructure that is substantially beta. The metastable beta can be strengthened considerably by heat treatment.

Titanium is used in corrosive environments or in applications that require light weight, high strength-to-weight ratio, and nonmagnetic properties. While commercially available in many alloys, most requirements can be met by a grade of commercially pure titanium, titanium-0.2% palladium alloy, or by the high-strength Ti-Al-V-Cr (beta type) alloys. These grades, which are available in most common wrought mill forms, are covered by ASTM-AMS specifications and, in most cases, by a similar ASME specification.

Like stainless steel, titanium sheet and plate work harden significantly during forming. Minimum bend-radius rules are nearly the same for both, although springback is greater for titanium. Commercially pure grades of heavy plate are cold formed or, for more severe shapes, warm formed at temperatures to about 800°F. Alloy grades can be formed at temperatures as high as 1,400°F in inert-gas atmospheres. Tube can be cold bent to radii three times the tube OD, provided that both inside and outside surfaces of the bend are in tension at the point of bending. In some cases, tighter bends can be made.

Despite their high strength, some alloys of titanium have superplastic characteristics in the range of 1,500 to 1,700°F. The alloy used for most superplastically formed parts is the standard Ti-6Al-4V alloy. Several aircraft manufacturers are producing components formed by this method. Some applications involve assembly by diffusion bonding.

Titanium plates or sheets can be sheared, punched, or perforated on standard equipment. Titanium and Ti-Pd alloy plates can be sheared subject to equipment limitations similar to those for stainless steel. The harder alloys are more difficult to shear, so thickness limitations are generally about two-third those for stainless steel.

Titanium and its alloys can be machined and abrasive ground; however, sharp tools and continuous feed are re-

Modulus (10^6 psi) Tension	Torsion	Coef of thermal expansion (32-1,000°F) (10^{-6} in./in.-F°)	RT Thermal conductivity (Btu-ft/h-ft^2-°F)	RT Electrical resistivity (μohm/cm)	Typical applications
14.9	6.5	5.4	9.0	56	Corrosion-resistant components in chemical and marine equipment; air frame construction requiring mazimum formability.
15.1	6.5	5.4	9.8	60	Corrosion-resistant components in chemical, marine, and aircraft construction
14.9	6.5	5.4	9.5	56	Corrosions-resistant components in chemical equipment where environment is midly reducing or varies between oxidizing and reducing
16.0	7.0	5.3	4.5	157	Components requiring oxidation resistance, good weldability, and strength at high temperature.
18.5	6.7	5.6	—	199	Used principally in jet engines to provide high-temperature strength and creep resistance.
16.5	6.1	3.9	3.9	171	The most versatile titanium alloy. Used in jet-engine, marine, and chemical-equipment components.
6.1	5.6	4.2	171		Similar to standard 6Al-4V except superior in fracture toughness and weldability.
15.0	6.0	5.4	—	—	Heavy sections requiring deep-hardening high strength with good fracture toughness; airframe components, fasteners, torsion bars, and springs.

Also has excellent cryogenic properties and resistance to salt-water corrosion.

quired to prevent work hardening. Tapping is difficult because the metal galls. Coarse threads should be used where possible.

Titanium castings can be produced by investment or graphite-mold methods. Casting must be done in a vacuum furnace, however, because of the highly reactive nature of titanium in the presence of oxygen. Typical applications for titanium castings are surgical implants and hardware for marine and chemical equipment such as compressors and valve bodies.

Generally, titanium is welded by gas-tungsten arc (GTA) or plasma-arc techniques. Metal inert-gas processes can be used under special conditions. Thorough cleaning and shielding are essential because molten titanium reacts with nitrogen, oxygen, and hydrogen, and will dissolve large quantities of these gases, which embrittles the metal. In all other respects, GTA welding of titanium is similar to that of stainless steel. Normally, a sound weld appears bright silver with no discoloration on the surface or along the heat-affected zone.

Zinc

Zinc, a crystalline metal with moderate strength and ductility, is seldom used alone except as a coating. In addition to its metal and alloy forms, zinc also extends the life of other materials such as steel (by hot dipping or electrogalvanizing), rubber and plastics (as an aging inhibitor), and wood (in paints). Zinc is also used to make brass, bronze, and die-casting alloys in plate, strip, and coil; foundry alloys; superplastic zinc; and activators and stabilizers for plastics.

Casting alloys: Zinc-casting alloys can be grouped into two general categories: standard zinc die-casting alloys, and the newer ZA (zinc-aluminum) casting alloys.

Zinc alloys—physical properties

	Die-casting alloys	Gravity casting alloys	WROUGHT ALLOYS Commercial 0.08 Pb	Copper-hardened 0.25% Cu	0.6% Cu-0.1% Ti	Superplastic zinc
Melting temperature (F°)	717-728	707-903	786	792	792	785-896
Coefficient of thermal expansion (10^{-6} in./in.-°F)	15.2	12.9-15.5	18,* 13†	19,* 11†	14,* 11†	11-16
Thermal conductivity (Btu-ft/h-ft^2-°F)	65.3	66.3-72.5	62.2	60.5	60.5	—
Electrical resistivity (microhm-cm)	6.4-6.5	5.8-6.2	6.0-6.1	6.2	6.2	—
Density (lb/in.^{3})	0.240	0.181-0.227	0.258	0.259	0.258	0.188

*Longitudinal (with grain) direction. †Transverse (cross-grain) direction.

Standard die-casting alloys: For pressure die casting, the established zinc alloys are the No. 3, 5, and 7 Zamak alloys. As die castings, they have good general-purpose tensile properties and can be cast in thin sections and with good dimensional accuracy. The alloys are often selected for plated or highly decorative applications because of their excellent finishing characteristics. Three major end-use areas for zinc die-cast components are automotive, building hardware, and electrical.

Zamak alloys contain approximately 4% aluminum with low percentages of magnesium, copper, and sometimes nickel. Impurities such as tin, lead, and cadmium are carefully controlled. These alloys are not recommended for gravity casting. They are cast by the hot-chamber die-casting process, which is different from, and more efficient than, the cold-chamber die-casting process commonly used for aluminum. In addition, a specialized process is used for efficient production of miniature die-cast components, using these alloys as well as ZA-8.

Typical tolerances of zinc die-cast parts are ±0.0015 in./in. for the first inch with an additional ±0.002 in./in. for larger parts. New zinc-casting technology allows for thin walls down to 0.025 in., improved internal soundness, and surface finishes that range typically from 32 to 64 rms.

Part dimensions change slightly when zinc die castings are aged. Zamak alloys No. 3 and 7 can shrink about 0.0007 in./in. after several weeks at

Zinc foundry alloys

	ZA-12			ZA-27			ZA-8		
	Sand	Perm mold	Die cast	Sand	Sand (HT*)	Die cast	Sand	Perm mold	Die cast
Tensile strength (10^3 psi)	40-45	45-50	57-60	58-64	45-47	59-64	36-40	32-37	53-56
Yield strength (10^3 psi)	30	36-40	45-48	53	37	52-55	28	30	41-43
Elong in 2 in. (%)	1-3	1-3	4-7	3-6	8-11	1-3	1-2	1-2	6-10
Tensile modulus (10^6 psi)		12		10.9	11.5	12		12.4	
Electrical conductivity (% IACS)		28.3			29.7			27.7	
Thermal cond (Btu-ft/h-ft^2-°F)		67			72.5			66.3	
Hardness, Bhn	92-96	105-125	95-105	110-120	90-100	116-122	90-100	85-90	99-107
Density (lb/in.^{3})		0.218			0.181			0.230	
Melting range (°F)		710-810			708-903			707-759	
Nominal composition (%)		11 Al, 0.75 Cu, 0.02 Mg, Bal Zn			27 Al, 2.2 Cu, 0.015 Mg, Bal Zn			8.4 Al, 1.0 Cu, 0.02 Mg, Bal Zn	

*Heat-treated: 3 h at 610°F and furnace cool. Data, Eastern Alloys Inc.

room temperature. Alloy No. 5 responds similarly, but total shrinkage can be 0.0009 to 0.0024 in./in., followed by expansion of 0.0020 in./in. over a period of years. When it is necessary to bring these changes to completion within a short time after casting, a stabilizing treatment of 3 to 6 h at 212°F is recommended.

ZA casting alloys: Designated as ZA-8, ZA-12, and ZA-27 (the numerical suffix represents the approximate percent by weight of aluminum), the high-aluminum alloys differ radically from the standard Zamak alloys in composition, properties, and castability. Although the ZA alloys were first introduced for gravity casting (sand and permanent mold), they have expanded into pressure die castings as well as the new, precision graphite-mold process. Important: Alloys ZA-12 and ZA-27 must be cold-chamber die cast; alloy ZA-8 is hot-chamber castable.

Gravity casting into low-cost graphite permanent molds provides high-quality ZA castings with excellent precision, eliminating much machining. It is particularly competitive for production quantities of 500 to 15,000 parts/year, where die casting or plastic injection molding would be prohibitive because of tooling costs.

ZA alloys combine high strength and hardness (up to 60,000 psi and 120 Bhn), good machinability with good bearing properties, and wear resistance often superior to standard bronze alloys. ZA castings are now competing with cast iron, bronze, and aluminum because of various property and processing advantages.

Of the three alloys, ZA-12 is preferred for most applications, and particularly for gravity casting. However, ZA-27 offers the highest mechanical properties regardless of casting method. Both are excellent bearing materials. ZA-8, on the other hand, gives the best plating characteristics. Because of its hot-chamber die castability and high mechanical properties, ZA-8 is also used for high-performance applications where standard zinc alloys may be marginal. All ZA alloys offer superior creep resistance and performance at elevated temperatures com-

ZINC BEARINGS

Although zinc alloys have been used in Europe for many years for plain bearings, U.S. design engineers are only recently recognizing these metals as possible alternatives to traditional bronze. The key engineering advantages of zinc-alloy bearings are lower cost, longer life, a higher load-bearing capability, and better emergency (dry-running) characteristics. Zinc also offers benefits to foundries in the form of pollution-free handling and significant energy savings in melting and casting operations.

Zinc alloys—mechanical properties

	DIE-CASTING ALLOYS			WROUGHT ALLOYS					
				Commercial		Copper-hardened			
	Alloy 3	Alloy 5	Alloy 7	0.08% Pb		0.75% C		0.6% Cu-0.1° Ti	
	(UNS Z33522)	(UNS Z33530)	(UNS Z33521)	(Hot-rolled)	(Cold-rolled)	(Hot-rolled)	(Cold-rolled)	(Hot-rolled)	(Cold-rolle
Yield strength (10^3 psi)	—	—	—	—	—	—	—	—	—
Tensile strength (10^3 psi)									
As-cast or wrought	41	47.6	41	16.4-21.4* 20.1-26.3†	21,* 28†	19.2-31.0* 24.5-40.6†	26,* 35†	24.0-30.3* 31.6-43.5†	29* 40†
Aged 10 yr indoors	35	39.3	35	—	—	—	—	42*	37*
Impact str, Charpy unnotched									
(ft-lb) As-cast or wrought	43	48	40	—	—	—	—	—	—
Aged 10 yr indoors	41	40	41	—	—	—	—	—	—
Fatigue endurance limit									
10^8 cycles (10^3 psi)	6.8	8.2	—	2.5	—	6.1	—	—	—
Creep rate, 77°F, 10^3 psi (days/1%)	—	—	—	0.045	—	0.35	—	5-5,000	—
Elongation									
As-cast or wrought	10	7	14	42-70*	50†	24-62* 17.5-47†	5†	28-54* 16-47†	44†
Aged 10 yr indoors	16	13	16	—	—	—	—	21	60
Modulus of elasticity (10^6 psi)	—	—	—	—	—	—	—	—	—

*Longitudinal (with grain) direction. †Transverse (cross-grain) direction. §Creep strength, 10^3 psi, 77°F, 0.01%/1,000 h.

pared to the Zamak alloys.

Wrought alloys: Wrought-zinc alloys are available in rolled sheet, strip, foil, and as drawn rod or wire. With controlled rolling, zinc alloys can be tailored to meet a wide range of hardness, luster, and ductility requirements. Rolled zinc can be worked by common fabricating methods, and then polished, lacquered, painted, or plated.

When zinc alloys are formed in progressive presses, as in battery-shell manufacture, they are self annealing. After successive forming operations in nonprogressive presses, however, the alloys work harden and break. This can be overcome, in copper-free alloys, by intermediate annealing for 5 min in boiling water to which 20% glycerine has been added. Copper-bearing alloys should be heated 5 to 10 min at 350°F. The copper and titanium-containing alloy should be held at 390°F for about 15 min to bring about crystallization. Excessive exposure to higher temperatures should be avoided, however, to prevent grain growth, cleavage cracks, and property deterioration.

Highly workable and highly forgeable wrought-zinc alloys containing Ti, Al, Pb, Cd, Cu, or Fe in various quantities are easily machined. Forged or extruded parts are free from porosity and have good detail.

0.6% Cu-0.1% Ti (Extruded forged)	**12% Al-1% Cu** (Extruded forged)	**Superplastic Zinc** 22% Al
—	—	23-61
35	50-72	28-72
—	—	—
—	—	5-25
—	—	—
—	—	9.5-18
10§	3§	0.19-10§
30	13-18	7-98
—	—	—
13	14	6-14

Zirconium

Zirconium and zirconium alloys

	GRADE			
	702*	**704**	**705**	**706**
ASTM designation	R60702	R60704	R60705	R60706
Density (lb/in.^{3})	0.234	0.237	0.240	0.240
Melting temperature (°F)	3,365	3,360	3,344	3,344
Thermal conductivity (Btu-ft/hr-ft^2-°F)	13.0	8.0	10.0	10.0
Coef of thermal expansion (10^{-6} in./in.-°F)	3.2	3.6	3.5	3.5
Specific heat (Btu/lb-°F)	0.068	0.067	0.067	0.067
Electrical resistivity (microhm-cm)	40.0	74.0	55.0	55.0
Modulus of elasticity (10^6 psi)	14.4	14.0	14.0	14.0
Tensile strength (10^3 psi)				
At 73°F	65	70	85	80
At 600°F	18	20	48	—
Yield strength (10^3 psi)				
At 73°F	45	55	65	65
At 600°F	12	15	30	—
Elongation				
At 73°F	25	20	20	25
At 600°F	35	32	30	—

*Unalloyed grade.

In addition to resisting HCl at all concentrations and at temperatures above the boiling temperature, zirconium and its alloys also have excellent resistance in sulfuric acid at temperatures above boiling and concentrations to 70%. Corrosion rate in nitric acid is less than 1 mil/year at temperatures above boiling and concentrations to 90%. The metals also resist most organics such as acetic acid and acetic anhydride as well as citric, lactic, tartaric, oxalic, tannic, and chlorinated organic acids.

Relatively few metals besides zirconium can be used in chemical processes requiring alternate contact with strong acids and alkalis. However, zirconium has no resistance to hydrofluoric acid and is rapidly attacked, even at very low concentrations.

Zirconium alloys can be machined by conventional methods, but they have a tendency to gall and work harden during machining. Consequently, tools with higher than normal clearance angles are needed to penetrate previously work-hardened surfaces. Results can be satisfactory, however, with cemented carbide or high-speed steel tools. Carbide tools usually provide better finishes and higher productivity.

Mill products are available in four principal grades: 702, 704, 705, and 706. These metals can be formed, bent, and punched on standard shop equipment with a few modifications and special techniques. Grades 702 (unalloyed) and 704 (Zr-Sn-Cr-Fe alloy) sheet and strip can be bent on conventional press-brake or roll-forming equipment to a 5*t* bend radius at room temperature and to 3*t* at 200°C. Grades 705 and 706 (Zr-Cb alloys) can be bent to a 3*t* and 2.5*t* radius at room temperature and to about 1.5*t* at 200°C.

Zirconium has better weldability than some of the more common construction metals including some alloy steels and aluminum alloys. Low distortion during welding stems from a low coefficient of thermal expansion. Zirconium is most commonly welded by the gas-tungsten arc (GTAW) method, but other methods can also be used, including gas metal-arc (GMAW), plasma-arc, electron-beam, and resistance welding.

Welding zirconium requires proper shielding because of the metal's reactivity to gases at welding temperatures. Welding without proper shielding (argon or helium) causes absorption of oxygen, hydrogen, and nitrogen from the atmosphere, resulting in brittle welds. Although a clean, bright weld results from the use of a proper shielding system, discoloration of a weld is not necessarily an indication of its unacceptability. However, white deposits or a black color in the weld area are not acceptable. A bend test is usually the best way to determine acceptability of a zirconium weld.

Major uses for zirconium and its alloys are as a construction material in the chemical-processing industry. Applications include heat exchangers (for producing hydrogen peroxide, rayon, etc.), drying columns, pipe and fittings, pump and valve housings, and reactor vessels. ■

Technical assistance for the **Nonferrous metals** section was provided by: **Aluminum Association Inc.,** Washington, DC, Aluminum; **Aluminum Co. of America,** Pittsburgh, PA, Aluminum; **Brush Wellman Inc.,** Cleveland, OH, Beryllium, Copper; **Climax Molybdenum Co.,** Ann Arbor, MI, Refractory metals; **Dow Chemical U.S.A.,** Freeport, TX, Magnesium; **Eastern Alloys Inc.,** Maybrook, NY, Zinc; **Haynes International Inc.,** Kokomo, IN, Nickel; **Inco Alloys International,** Huntington, WV, Nickel; **KBI Div., Cabot Corp.,** Reading, PA, Refractory metals; **RMI Co.,** Niles, OH, Titanium; **Reynolds Aluminum, Reynolds Metals Co.,** Richmond, VA, Aluminum; **Teledyne, Wah Chang Albany,** Albany, OR, Zirconium; **Tin Research Institute,** Columbus, OH, Tin.

Ferrous metals

As the most abundant of all commercial metals, alloys of iron and steel continue to cover a broad range of structural applications.

Iron ore constitutes about 5% of the earth's crust and is easy to convert to a useful form. Iron is obtained by fusing the ore to drive off oxygen, sulfur, and other impurities. The ore is melted in a furnace in direct contact with the fuel using limestone as a flux. The limestone combines with impurities and forms a slag, which is easily removed.

Adding carbon in small amounts reduces the melting point (2,777°F) of iron. All commercial forms of iron and steel contain carbon, which is an integral part of the metallurgy of iron and steel. Manipulation of atom-to-atom relationships between iron, carbon, and various alloying elements establishes the specific properties of ferrous metals. As atoms transform from one specific arrangement, or crystal lattice, to another, strength, toughness, impact resistance, hardness, ductility, and other properties are altered. The metallurgy of iron and steel is a study of how these atomic rearrangements take place, how they can be controlled, and which properties are affected.

Ferrous metallurgy

All metals undergo a phase transformation when they change from one crystal arrangement to another. In the iron-carbon alloy system, an important phase transformation takes place between about 1,300 and 1,600°F. The exact temperature is determined by the amount of carbon and other alloying elements in the metal. Iron transforms from a face-centered cubic (FCC) structure — called the gamma phase, or austenite — at high temperature to a body-centered cubic (BCC) structure — alpha phase, or ferrite — at a lower temperature. In pure iron, this transformation (the A_3 transformation) is marked by a distinct increase in length as the metal cools below the critical temperature because the body-centered lattice is less compact than the face-centered lattice.

High-temperature austenite, an FCC structure, allows enough space for carbon to squeeze in between the iron atoms. Iron atoms maintain their place on the lattice and carbon atoms become "interstitials." In the low-temperature ferrite, or BCC structure, however, there is no room for carbon atoms. What happens to these carbon atoms determines many of the properties of

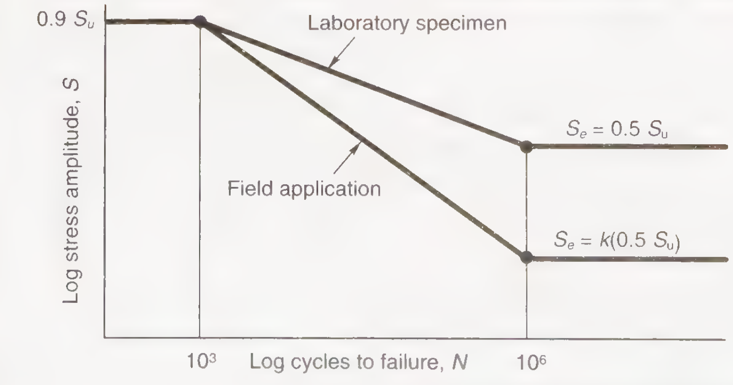
PREDICTING FATIGUE IN STEEL

The *S-N* curve relating applied *S* to number of cycles to failure *N* is often used to model fatigue behavior. Enough information has been compiled about fatigue in steel to allow us to approximate an *S-N* curve as shown here for any set of design conditions based on static tensile data without the need to perform dynamic fatigue tests. This is possible because *S-N* curves for steel — unlike most nonferrous metals — level off after a large number of cycles. The stress at this level, called fatigue endurance limit, which represents the maximum stress that the metal can withstand with a 50% probability of failure, is approximately related to ultimate tensile strength. Generally, this endurance limit occurs around 10^6 cycles.

A great number of tests indicate that the endurance limit S'_e for rotating-beam specimens varies from 40 to 60% of the ultimate tensile strength S_u for steels up to 200,000 psi.

To draw the curve, locate point S'_e at a life cycle of 10^6 cycles. A second point is plotted at 10^3 cycles corresponding to a fatigue strength that generally is observed to be 0.9 S_u. These two points define a curve that approximately predicts fatigue behavior of the laboratory steel specimen — based solely on the static variable S_u.

To relate this curve to real-life design conditions, introduce $k < 1$, a fatigue-strength reduction coefficient to account for factors that are known to influence fatigue, such as mean stress, corrosion environment, surface finish, stress concentration, size variations, frequency of loading, temperature, statistical scatter inherent in cycles-to-failure data, uncertainty in the mean *S-N* curve, and quality of workmanship, fabrication, or welding. The estimated endurance limit for the real-life application S_e becomes $S_e = k\ (0.5\ S_u)$. The resulting curves for both the laboratory specimen and the real-life field application — lowered by *k* — are shown here. The curves represent minimum, no mean value of strength.



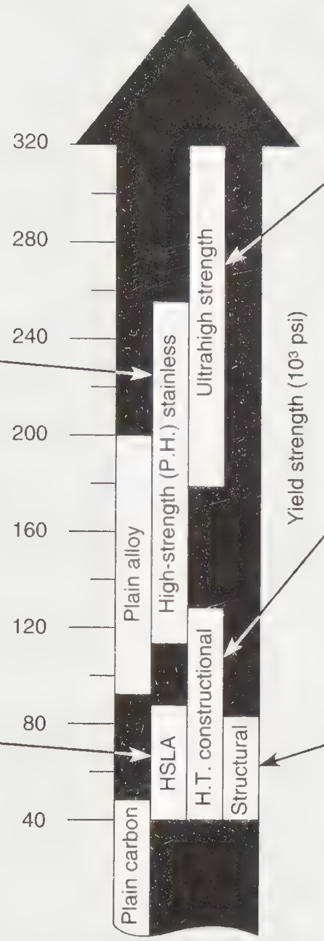
How surface finish affects fatigue life of steel

Finishing operation	Surface finish (μ in.)	Fatigue life (cycles)
Lathe	105	24,000
Partly hand polished	6	91,000
Hand polished	5	137,000
Ground	7	217,000
Ground and polished	2	234,000

For SAE 3130 steel, completely reversed bending at 95,000 psi. (See "Fatigue Failure in the Real World," MD, August 26, 1976).

SORTING OUT THE "HIGH-STRENGTH" STEELS

A number of steels have been developed for highly specialized, high-performance applications. Here is a thumbnail description of the major families of "high-strength" steels — when they are used and how they differ.



Precipitation-hardening or age-hardening stainless steels are available in most mill forms, and some grades are castable. These alloys are not limited to "structural" applications and are used whenever corrosion or wear resistance is required. In addition, some can be used to moderately high temperatures. (*See chapter on stainless steels.*)

Available in sheet and strip (also plate, "structural" shapes, and tube for some alloys), HSLA steels require no thermal treatment. They are formulated to compete with low-cost carbon steel or aluminum when unit cost, weight, and strength must be optimized. Auto parts, truck-frame parts, and architectural members are typical applications. (*See chapter on HSLA steels.*)

These are the strongest — but among the most costly — of all ferrous alloys. Available in most mill forms, these allows were developed to meet aerospace demands for the highest possible strength-to-weight ratio. These alloys, also not limited to "structural" applications, require heat treatment. (*See chapter on ultrahigh-strength alloys.*)

These grades are provided by the mill in quenched-and-tempered condition, so forming, welding, and machining should be minimized. Usually the constructional grades are available as plates only. They are used for tanks, offshore platforms, off-road vehicle panels, and as load-bearing plates on heavy-duty equipment.

The "structural" grades are available in forms such as flanged beams, channels, and angles and are used for high-strength vehicle frame parts, bridges, and construction members. Strength versus cost are usually considered before these steels are selected to replace mild carbon and alloy steels. Most structural grades are used "as-rolled" and require no thermal treatment to develop strength.

iron and steel.

For example, during the slow cooling of a low-carbon steel such as AISI 1020 (0.20% carbon), transformation begins as the metal reaches 1,555°F. The first metal to reach this temperature transforms to ferrite, the BCC structure, and expels the interstitial carbon into the remaining regions of austenite. As the metal cools further, more iron transforms into ferrite, leaving less austenite and more regions rich in expelled interstitial carbon.

Finally, at about 1,350°F, the lower end of the transformation temperature range for 1020 steel, the last remaining austenite tries to transform — in spite of the rich carbon concentrations. At this point, two things occur: The carbon bonds with available iron atoms to form Fe_3C, an intermetallic compound called cementite, or iron carbide, and it precipitates out as a discrete structure; the remaining austenite then transforms to ferrite.

The structure that results from this final transformation is a lamination consisting of alternating layers of ferrite and iron carbide. Of course, the portions of metal that transformed previously remain as large islands of pure ferrite. The laminated structure formed at the last moment is called pearlite. The combined structure of ferrite and pearlite is soft and ductile — steel in its lowest-strength condition.

In contrast, when ferrous alloys are cooled rapidly, or quenched, expelled carbon atoms do not have time to move away from the iron as it transforms to ferrite. The steel becomes so rigid that, before the carbon atoms can move, they become trapped in the lattice as the iron atoms try to transform to the body-centered cubic structure. The result is a body-centered tetragonal structure in which the carbon atom is an interstitial member. Steel that has undergone this type of transformation is martensitic. Naturally, martensite is in a state of unequilibrium, but it owes much of its high strength and hardness (and lower ductility) to its distorted, stressed lattice structure.

A number of heat-treatment cycles have been developed to alter the structure of steel. For example, when martensite is tempered (heated below A_3 temperature) some internal stresses are relieved, and the resulting structure has more ductility than as-quenched martensite.

Other heat treatments change the proportions of pearlite and martensite; some even entrap austenite at room temperature. Others alter or reduce the size of the grains or pattern of these structures, providing improved strength or toughness. And when other alloying elements — including boron, nickel, chromium, manganese, silicon, and vanadium — are added to the metal, the behavior of ferrous alloys, as they transform from one structure to another, is further complicated. But because the structure of steel — and thus, the mechanical properties of steel

— can be altered in so many ways, ferrous alloys can be developed to suite an extremely wide variety of design needs.

High-strength steel

Developed primarily for high-strength applications, these steels are usually heat-treated alloys that provide strengths at least equal to those of as-rolled steel. Heat-treated constructional alloy steels and the ultrahigh-strength steels are used in applications where high strength can be converted to a weight-saving advantage over other steels.

High-yield-strength, quenched-and-tempered constructional alloy steels are usually heat treated at the mill to develop their properties so they require no further heat treatment by the fabricator. Although these heat-treated alloy steels are available in all conventional product forms, they are most common in plate products. Some grades are also available as abrasion-resistant (AR) modifications. In these conditions, high hardness is the desired property, with some toughness being sacrificed.

Over 20 types of these proprietary high-strength alloy steels are produced. Some have been developed to combine improved welding characteristics along with high strength. Most have good impact properties in addition to high strength. An example of the high-yield-strength grades in this class is HY-80/100, which is used for naval vessels. This material combines high strength and toughness with weldability.

Ultrahigh-strength steels start with grade 4340 and are modifications of this alloy. When these steels are used for aerospace components, they are usually produced by the vacuum-arc-remelt (VAR) process. Steels commonly considered to be in the ultrahigh-strength category have yield strengths greater than 180,000 psi. They are classified into several broad categories based on chemical composition or metallurgical-hardening mechanisms.

Medium-carbon alloy steels are generally modifications of grade 4330 or 4340 (usually with increased molybdenum, silicon, and/or vanadium). These grades provide excellent hardenability in thick sections.

Modified tool steels of the 5% Cr, 1% Mo, 1% V hot-work die-steel variety (H11 modified, H13) provide the next step in increased hardenability and greater strength. Most steels in this group are air hardened in moderate to large sections and, therefore, are not likely to distort or quench crack. Structural uses of these steels are not as widespread as they once were, mainly because of the development of other steels costing about the same but offering greater fracture toughness.

Maraging steels contain 18% nickel, along with appreciable amounts of molybdenum, cobalt, and titanium, and almost no carbon. These alloys can be strengthened significantly by a precipitation reaction at a relatively low temperature. They can be formed and machined in the solution-annealed condition but not without difficulty. Weldability is excellent. They can be heat treated to 250 to 300-ksi yield strength with a simple 900°F aging treatment. Fracture toughness of the maraging steels is considerably higher than that of the conventional high-strength steels.

Maraging steels are used in a variety of high-performance applications, and most extensively in aircraft and tooling components.

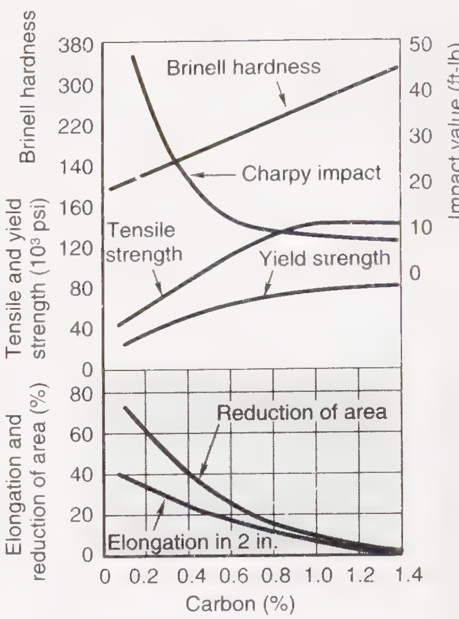
The 9% Ni, 4% Co alloys were designed to provide high strength and toughness at room temperature as well as at moderately elevated temperatures — to about 800°F. Weldability and fracture toughness are good, but the alloys are susceptible to hydrogen embrittlement. These steels are used in airframes, gears, and large aircraft parts.

Carbon steel

Carbon steel, also called plain carbon steel, is a malleable, iron-based metal containing carbon, small amounts of manganese, and other elements that are inherently present. Steels can either be cast to shape or wrought into various mill forms from which finished parts are formed, machined, forged, stamped, or otherwise shaped.

Cast steels are poured to near-final shape in sand molds. The castings are then heat treated to achieve specified properties and machined to required dimensions.

Wrought steel undergoes two operations. First, it is either poured into ingots or strand cast. Then, the metal is reheated and hot rolled into the finished, wrought form. Hot-rolled steel is characterized by a scaled surface and a decarburized skin. Hot-rolled bars may be subsequently finished in a two-part process. First, acid pickling or shot blasting removes scale. Then, cold drawing through a die and restraightening improves surface properties and strength. Hot-rolled steel may also be cold finished by metal-removal processes such as turning or grinding. Wrought steel can be subsequently heat treated to improve machinability or to adjust mechanical properties.



How mechanical properties *of carbon steels vary with carbon content. Data represent as-rolled, 1-in.-diameter bars.*

Carbon steels may be specified by chemical composition, mechanical properties, method of deoxidation, or thermal treatment (and the resulting microstructure).

Composition: Wrought steels are most often specified by composition. No single element controls the characteristics of a steel; rather, the combined effects of several elements influence hardness, machinability, corrosion resistance, tensile strength, deoxidation of the solidifying metal, and microstructure of the solidified metal.

Effects of carbon, the principal hardening and strengthening element in steel, include increased hardness and strength and decreased weldability and ductility. For plain carbon steels, about 0.2 to 0.25% C provides the best machinability. Above and below this level, machinability is generally lower for hot-rolled steels.

Standard wrought-steel compositions (for both carbon and alloy steels) are designated by an AISI or SAE four-digit code, the last two digits of which indicate the nominal carbon content. The carbon-steel grades are:

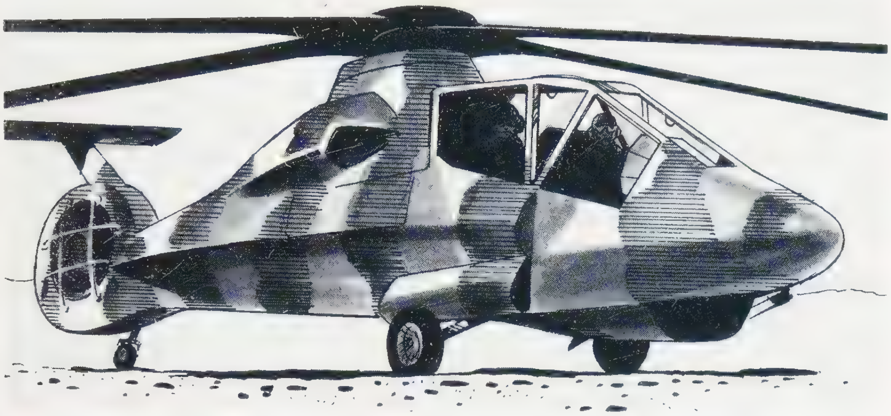
10xx: Plain carbon
11xx: Resulfurized
12xx: Resulfurized and rephosphorized
15xx: Nonresulfurized, Mn over 1.0%

The letter "L" between the second and third digits indicates a leaded steel; "B" indicates a boron steel.

Cast-carbon steels are usually specified by grade, such as A, B, or C. The A

These specialty metals meet tougher demands with unique blends of characteristics.

New or improved specialty metals are giving design engineers additional resources to work with as they search for more effective solutions to today's technological requirements. Some recent examples of this ongoing effort can be found in the following reports from Carpenter Technology's Application Engineering Service.



Award-winning alloy selected for next-generation aircraft programs.

Carpenter AerMet® 100 alloy was recently named by R&D magazine as one of the 100 most significant inventions of the past year. An illustration of its contribution to new product developments is the fact that the alloy will be used in the Army LHX (light helicopter experimental) program.

AerMet 100 alloy, which will be used for the main actuators, is the only material with the superior ballistic tolerance and superior stress corrosion cracking resistance demanded by the critical components.

In a related development, another Carpenter alloy will be used to build the next-generation Army helicopter, the RAH-66 Comanche. Pyrowear® 53 alloy will be used for all transmission gearing, and possibly the free wheel limits. Its superior temperature capability and high gear tooth fatigue resistance were deciding factors in the alloy's selection.

Super-clean stainless alloy meets both semi-conductor and pharmaceutical standards.

Manufacturers of semi-conductors and pharmaceuticals are placing increased emphasis on internal cleanliness of the materials they use. Better surface finishes on the inside diameter of seamless tubing and fittings will help to maintain purity and enhance product yields. To meet these cleanliness requirements, Carpenter has cooperated with customers in the development of Type 316L-SCQ™ stainless. This alloy should be of particular interest to customers who require exceptionally pure material for valves, fittings, glands and similar products.

Several premium melting techniques are used to produce this alloy, which is available through two programs. One offers "intermediate sulfur" (0.005–0.015%), produced by AOD (argon-oxygen decarburization air melting) plus VAR (vacuum arc remelting). The other uses double vacuum melting, VIM (vacuum induction melting) plus VAR (vacuum arc remelting) to produce material with 0.005% maximum sulfur.

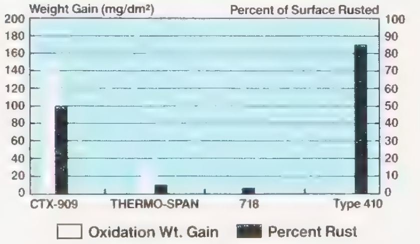
New, controlled-expansion alloy resists oxidation in temperatures to 1300°F.

Carpenter's new Thermo-Span™ alloy can now be evaluated for applications such as casings, rings and seals in turbine engines, and other uses where ease of fabrication and environmental resistance are required. This is because the new alloy combines the best features of earlier controlled expansion superalloys with greatly improved oxidation resistance. Thermo-Span alloy is being evaluated for use in operating temperatures to 1300°F. without a protective coating, which could result in considerable savings to users.

In Figure 1, four alloys were tested for oxidation resistance. Thermo-Span alloy ranked second to Pyromet® 718 alloy, containing 19% Cr. In Figure 2, the expansion coefficients of Thermo-Span alloy and CTX-909 superalloy are shown with dilation curves.

Figure 1

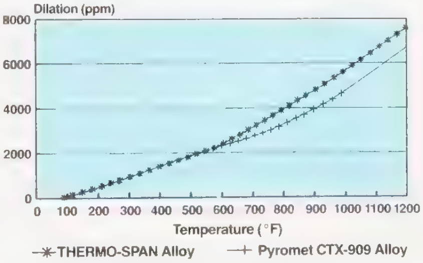
Comparison of Oxidation and Salt Fog Test Results for Four Alloys



Oxidation Test: 1250°F/100h
Salt Fog Test: 95°F/200h

Figure 2

$\Delta L/L_0$ Curves for THERMO-SPAN Alloy and Pyromet CTX-909 Alloy



(Heating Rate: 5.4°F/min. Reference: 77°F)

Please circle the reader service card number for information about Carpenter's Application Engineering Service. Or, for FREE literature specific to the alloys and applications described here, call toll-free: 1-800-527-6900.

CARPENTER TECHNOLOGY
CARPENTER STEEL DIVISION
READING, PENNSYLVANIA 19612
CarTech®

Circle 607

A NEW GUIDE

24 Specialty Metal Alloys from Carpenter Technology to meet your specific requirements.

REQUIREMENTS/ CHARACTERISTICS	HAVE BEEN USED IN APPLICATIONS LIKE THESE	CONSIDER
Austenitic stainless which possesses superior self-mated galling and metal-to-metal wear resistance. Comparable corrosion resistance to Type 304 with higher strength and oxidation resistance.	Consider for chain link conveyor belts, luggage carousels in air terminals, fasteners, fittings for pumps and valves.	**Gall-Tough™** gall resistant stainless.
Good toughness and corrosion resistance. Good longitudinal and transverse properties in large sections. Age hardenable by low temperature treatment.	Valve parts, fittings, cold headed and machined fasteners, shafts, landing gear parts, aircraft and nuclear reactor components, and petrochemical applications.	**PH 13-8 Mo*** precipitation hardening stainless. (*Reg. trademark of Armco, Inc.)
Corrosion resistance comparable to that of Type 304. A yield strength of 100 ksi in the annealed condition. One step heat treatment develops a yield strength of 175 ksi. Readily fabricated.	Pump impellers, shafts, valve bodies, fittings, rods and other process equipment components.	**Custom 450®** martensitic, precipitation hardening stainless.
Exceptionally high strength, high hardness. Age-hardenable. Good corrosion resistance. Readily fabricated.	Valve stems, seals, components, retaining rings, shafts and fasteners.	**Custom 455®** martensitic, precipitation hardening stainless.
Excellent corrosion resistance with high strength and hardness. Age hardenable in a single step, low temperature treatment.	Oil field valve parts, chemical process equipment, aircraft and missile fittings, fasteners, pump shafts, gears, paper mill equipment.	**Custom 630 (17Cr-4Ni)** martensitic precipitation hardening stainless.
Premium quality boron stainless provides a high thermal neutron absorption cross-section along with high ductility.	Used in nuclear industry for spent fuel storage racks and cask baskets, control rods, burnable poison and shielding.	**NeutroSorb PLUS** modified Type 304 Stainless with boron.
Excellent resistance to more than 150 harsh corrodents, including hot sulfuric acid. Virtually immune to stress-corrosion cracking. Readily fabricated.	Mixing tanks, process piping, heat exchangers, pickling equipment, pump shafts, bolts, valve stems, fittings and fasteners.	**20 Cb-3®** austenitic stainless.
An austenitic stainless steel which is resistant to hot chloride environments with low pH. Good resistance to pitting, crevice corrosion and stress-corrosion cracking in chloride environments.	Heat exchangers, piping, mixing tanks, pickling tanks, fume scrubbers, wet process phosphoric acid environments.	**20 Mo-6®** stainless.
Superior resistance to intergranular corrosion, pitting, chloride stress-corrosion cracking, and nitric acid attack on welded seams. More than twice the annealed yield strength of typical austenitic stainless steels.	Heat exchangers in petroleum refining, petrochemical, chemical, pulp and paper, and allied processing industries.	**7-Mo PLUS®** duplex stainless.
Developed for use in highly corrosive environments where chloride ion pitting is of concern. Good resistance to chloride stress-corrosion cracking. Readily fabricated.	Chemical processing, power plant condenser, and offshore platform heat exchangers using seawater. Tanks, shells, tubes, pipes and other chemical process components.	**AL-6XN*** superaustenitic stainless. (*Reg. trademark of and used under license fro Allegheny Ludlum Corp.)
Magnetic components needing corrosion resistance superior to that of pure iron, low carbon steel and silicon-iron alloys . . . without the substantial decrease in saturation induction associated with 18% Cr ferritic stainless steels. May be blanked, formed and cold drawn. Cold working will increase hardness.	Electromechanical devices requiring some degree of corrosion resistance, either in service or for extended shelf life without the need for protective coatings. Automotive components, such as fuel injectors, fuel pump motor laminations and ABS solenoids.	**Carpenter Chrome Core™ 8 alloy** or **Carpenter Chrome Core 12 alloy** ferritic stainless steel. (Also available in free machining versions)

For free technical literature on these alloys, which are typical of those developed for special applications, circle the response card number ndicated or call 800-527-6900. Or, contact your ocal Carpenter Service Center to discuss your specific requirements.

CARPENTER TECHNOLOGY

CARPENTER STEEL DIVISION • READING, PA 19612

CarTech®

REQUIREMENTS/ CHARACTERISTICS	HAVE BEEN USED IN APPLICATIONS LIKE THESE	CONSIDER
A tough, corrosion-resistant nickel-cobalt alloy strengthened by carbon, chrome and molybdenum. Equal to 300M alloy in strength with increased fracture toughness and stress-corrosion-cracking resistance.	Aircraft landing and arresting gear components, engine shafts, high-strength bolts and gun breeches.	**AerMet™ 100 Alloy**
Die-casting die steel. Superior to conventional Type H-13. Offers improved isotropic properties for greater uniformity and better structural integrity. Can be certified to ADCI Specification 01-83-02D, and to Chrysler Corporation NP2080.	Die-casting dies.	**883 PLUS® Alloy**
Offers significantly greater life expectancy for repetitive, high volume and intricate shape aluminum extrusion work than Type H-13.	Aluminum extrusion dies, mandrels and other tooling.	**Extendo-Die® Alloy**
Capable of being heat treated to show very high initial permeabilities, maximum permeabilities and AC core losses at low magnetic flux densities.	Toroids in the manufacture of core components.	**HyMu "800"®** Nickel-Molybdenum Alloy.
High magnetic saturation for high permeability values at very high magnetic flux densities.	Aircraft motors and generators, transformer laminations and tape toroids.	**Hiperco® "50" Alloy**
Thermal expansion characteristics approximately 1/10th that of carbon steel at temperatures up to 400°F. Readily fabricated.	Radar and electronic devices, aircraft controls, rod and tube assemblies for temperature regulators.	**Invar "36"®** nickel-iron alloy.
Hermetic glass and ceramic sealing characteristics for the harder Pyrex glasses and ceramic materials. Meets requirements of ASTM Spec. F15-61T. Readily fabricated.	Power and microwave tubes, transistors, diodes, and integrated circuits.	**Kovar®** glass/ceramic sealing alloy.
This specially designed carburizing alloy has useful properties in high temperature applications. It provides high impact strength and fracture toughness.	Gears operating in high temperature environments, such as transmissions for helicopters and aircraft.	**Pyrowear® Alloy 53**
A nonmagnetic alloy with this unique blend of properties: strength to 300 ksi, good ductility, toughness, excellent corrosion resistance.	Fastener stock and components in medical, marine, oil and gas well, chemical, food processing and nonmagnetic electrical products and springs.	**MP35N*** Nickel-Cobalt-Chromium Molybdenum Alloy. (*Reg. trademark of SPS Technologies, Inc.)
Exceptionally high yield, tensile and creep-rupture properties at temperatures up to 1300°F. Can be annealed and welded without spontaneous hardening during heating and cooling.	Jet engine parts, such as wheels, buckets and spacers, airframe parts, and high temperature bolts and fasteners.	**Pyromet® 718** precipitation hardenable, nickel-base alloy.
A high strength precipitation hardenable superalloy. Exhibits a low coefficient of thermal expansion with high strength at temperatures to 1200°F (649°C). High hot hardness and good thermal fatigue resistance.	Gas turbine engine components, hot work die applications, ordnance hardware, steam turbine blades, gauge blocks, springs, and rocket thrust chambers.	**Pyromet Alloy CTX-3**
A nickel base alloy offering exceptional resistance to pitting, crevice, general corrosion and stress-corrosion cracking in the age hardened (high strength) condition. Yield strength above 120 ksi obtained without prior warm or cold working.	Should be considered for corrosive environments encountered in sour gas, refinery and chemical process applications.	**Custom Age 625 PLUS Alloy**

Circle 607

Quality, performance, service depend on metals with special properties.

Industry's ability to improve product quality or utilize more efficient manufacturing processes depends, to a great extent, on the new or improved specialty metals available to design engineers. Here are some recent examples of such materials, as reported by Carpenter's Application Engineering Service:

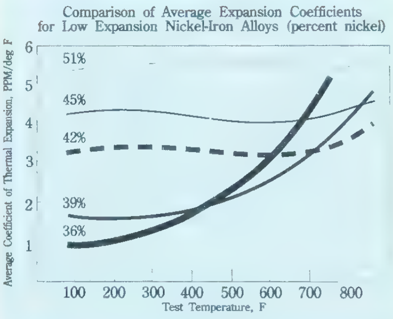
Composite curing temperatures require tooling materials that match thermal expansion.

Photo courtesy of Boeing Company

The increasing use of non-metallic composite structures has posed a challenge to toolmakers. In addition to the size and complexity of many composite structures, the coefficient of thermal expansion of tooling materials is now a primary consideration in the selection of materials for tooling molds.

Low-thermal-expansion, nickel-iron tooling materials, such as Carpenter Invar "36"® alloy, have been used successfully for these situations. The photo shows a typical application, layup tooling for a graphite-epoxy aircraft part. Because it is autoclaved with the composite assembly, the tool's coefficient of thermal expansion (CTE) must closely match that of the composite. The nickel-iron alloy can do this. It also offers other advantages, including ductility, ready fabricability and good mechanical properties.

Thermal expansion of Ni-Fe alloys changes significantly as nickel content is varied. The chart compares average expansion coefficients for a number of these alloys which contain between 30% and 50% nickel.



Some wire applications demand exceptionally high strength with superior corrosion resistance.

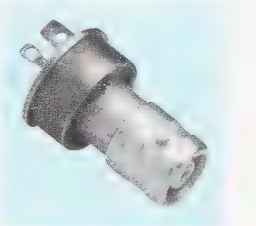
A unique combination of properties makes Carpenter 20Mo-6® HS stainless a material that merits consideration where corrosion resistance and ultra high tensile strength are desired. It offers exceptional resistance to environmental cracking and chloride-induced pitting and crevice corrosion . . . and remains nonmagnetic after work hardening. This HS grade is the result of compositional and processing modifications made to Carpenter 20Mo-6 stainless.

It has been used for cold-drawn rod and wire applications, such as single-strand wireline and armoring wire for oil and gas wells, springs, yacht rigging and nonmagnetic cables.

Corrosion resistant magnetic & electromechanical components provide extended service.

A family of controlled chemistry, ferritic 8% and 12% chromium-iron alloys has been considered for use in automotive components such as fuel injectors, fuel pump motor laminations and ABS solenoids. Carpenter Chrome Core™ 8 and 12 are intended for use in magnetic components where corrosion resistance superior to that of pure iron, low carbon steel and silicon-iron alloys is desired, without the substantial decrease in saturation induction associated with 18% Cr ferritic stainless steels. Applications could include electro-mechanical devices requiring some degree of corrosion resistance, either in service, or for extended shelf life without the need for protective coatings.

Each chrome level is available in both a standard and a free-machining grade.



Automotive fuel injector

Please circle the reader service card number for information about Carpenter's Application Engineering Service. Or, for FREE literature specific to the alloys and applications described here, call toll-free: 1-800-527-6900.

CARPENTER TECHNOLOGY
CARPENTER STEEL DIVISION
READING PENNSYLVANIA 19612
CarTech

Circle 607

Rolled and drawn carbon steels — mechanical properties

	1015, 1020, 1022			1035, 1040			1045, 1050			1095		
	Hot rolled	Cold drawn	Annealed (1,600°F)	Hot rolled	Cold drawn	Quenched and tempered	Hot rolled	Cold drawn	Quenched and tempered	Hot rolled	Cold drawn, annealed (1,450°F)	Quenched and tempered
Yield strength (10^3 psi)	48	51	43	60	71	63.96	60	84	68-117	83	55	80-152
Tensile strength (10^3 psi)	65	61	57	90	80	96-130	105	95	105-137	140	95	130-216
Elongation in 2 in. (%)	36	15	37	25	12	17-24	20	10	25-15	9	13	10-20

Approximate properties based on 1-in. cross section; larger sections have lower mechancial properties. These steels generally are not selected for fatigue applications, so data on fatigue are not available. Properties vary with quench medium and temper time and temperature.

grade (also LCA, WCA, AN, AQ, etc.) contains 0.25% C and 0.70% Mn maximum. B-grade steels contain 0.30% C and 1.00% Mn, and the C-grade steels contain 0.25% C and 1.20% Mn. These carbon and manganese contents are designed to provide good strength, toughness, and weldability. Cast carbon steels are specified to ASTM A27, A216, A352, or A487.

ast structural-grade carbon teels — mechanical properties

	GRADE (min tensile strength)		
	60,000	65,000	70,000
ensile strength (10^3 psi)	63	68	75
ield point (10^3 psi)	35	38	42
longation in 2 in. (%)	30	28	27
ardness, Bhn	131	131	143
mpact strength, Charpy (ft-lb)			
At 70°F	12	35	30
At 40°F	5	12	12
ndurance limit (10^3 psi)			
Unnotched	30	30	35
Notched	19	19	22

arbon steels — physical properties

	Wrought	Cast
elting temperature (°F)	2,750-2,775	2,750-2,775
oefficient of thermal expansion (10^{-6}in./in.-°F) 70-1,200°F	8.1-8.4	8.0-8.3
hermal conductivity Btu-ft/hr-ft^2-°F)	27	27
ensity (lb/in.^{3})	0.283	0.283
lectrical resistivity (microhm-cm)	17-19	15-16

Microalloying technology has created a new category of steels, positioned both in cost and in performance between carbon steels and the alloy grades. These in-between steels consist of conventional carbon steels to which minute quantities of alloying elements — usually less than 0.5% — are added in the steelmaking process to improve mechanical properties. Strength and hardness are increased significantly.

Any base-grade steel can be microalloyed, but the technique was first used in sheet steel a number of years ago. More recently, microalloying has been applied to bar products to eliminate the need for heat-treating operations after parts are forged. Automotive and truck applications include connecting rods, blower shafts, stabilizer bars, U-bolts, and universal joints. Other uses are sucker rods for oil wells and anchor bolts for the construction industry.

Mechanical properties: Cast and wrought products are often specified to meet distinct mechanical requirements in structural applications where forming and machining are not extensive. When steels are specified by mechanical properties only, the producer is free to adjust the analysis of the steel (within limits) to obtain the required properties. Properties may vary with cross section and part size.

Mechanical tests are usually specified under one of two conditions: mechanical test requirements and no chemical limits on any element, or mechanical test requirements and chemical limits on one or more elements, provided that such requirements are technologically compatible.

Method of deoxidation: Molten steel contains dissolved oxygen — an important element in the steelmaking reaction. How this oxygen is removed or allowed to escape as the metal solidifies determines some of the properties of the steel. So in many cases, "method of deoxidation" is specified in addition to AISI and SAE chemical compositions.

For "killed" steels, elements such as aluminum and silicon may be added to combine chemically with the oxygen, removing most of it from the liquid steel. Killed steels are often specified for hot forging, carburizing, and other processes or applications where maximum uniformity is required. In sheet steel, aging is controlled by killing — usually with aluminum. Steels intended for use in the as-cast condition are always killed. For this reason, steels for casting are always fully deoxidized.

On the other hand, for "rimmed" steels, oxygen (in the form of carbon monoxide) evolves briskly throughout the solidification process. The outer skin of rimmed steels is practically free from carbon and is very ductile. For these reasons, rimmed steels are often specified for cold-forming applications. Rimmed steels are often available in grades with less than 0.25% C and 0.60% Mn.

Segregation — a nonuniform variation in internal characteristics and composition that results when various alloying elements redistribute themselves during solidification — may be pronounced in rimmed steels. For this reason, they are usually not specified for hot forging or for applications requiring uniformity.

"Capped" and "semikilled" steels fall between the rimmed and killed steels in behavior, properties, and degree of oxidation and segregation. Capped steels, for example, are suited for certain cold-forming applications because they have a soft, ductile, surface skin, which is thinner than rimmed-steel skin. For other cold-forming applications, such as cold extrusion, killed steels are more suitable.

Microstructure: The micro-

EXPENDABLE-PATTERN CASTING

This full-mold casting process is modified, so mass production becomes practical. The process turns out castings in large quantities that have smoother surfaces and finer microstructures than those cast by conventional methods. Although today's full-mold casting method is based on the same principle of using expendable polystyrene patterns, the process has grown considerably more sophisticated. Many improvements have been made, but the main, bottom-line change is that the process is now practical and economical as a production process for making thousands of quality, smooth-surface castings in both ferrous and nonferrous metals.

structure of carbon and alloy steels in the as-rolled or as-cast condition generally consists of ferrite and pearlite. This basic structure can be altered significantly by various heat treatments or by rolling techniques. A spheroidized annealed structure would consist of spheroids of iron and alloy carbides dispersed in a ferrite matrix for low hardness and maximum ductility, as might be required for cold-forming operations. Quenching and tempering provide the optimum combination of mechanical properties and toughness obtainable from steel. Grain size can also be an important aspect of the microstructure. Toughness of fine-grained steels is generally greater than that of coarse-grained steels.

Free-machining carbon steels — mechanical properties

	12L 13/12L14 (+Te, Se, or Bi) — 12L 15 —		— 1211, 1212, 1213 —		— 1117, 1118, 1119 —			— 1137 —		— 1141, 1144 —			
	Hot rolled	Cold drawn	Hot rolled	Cold drawn	Hot rolled	Cold drawn	Quenched and tempered*	Hot rolled	Cold drawn	Quenched and tempered†	Hot rolled	Cold drawn	Quenche and tempered
Yield strength (10^3 psi)	34	60-80	33	58	34-46	51-68	50-76	48	82	136	51	90	163
Tensile strength (10^3 psi)	57	70-90	55	75	62-76	69-78	89-113	88	98	157	94	100	190
Elongation in 2 in. (%)	22	10-18	25	10	23-33	15-20	17-22	15	10	5	15	10	9
Machinability (170 sfpm = 100%)	136-205		114-168				82-106			71			69

Based on 3/4 to 1 1/4-in. bars. Single values are minimum properties. *Quenched and tempered at 350°F.
†Oil quenched and tempered at 400°F, average properties.

Free-machining steels: Several free-machining carbon steels are available as castings and as hot-rolled or cold-drawn bar stock and plate. Machinability in steels is improved in several ways, including:

- Addition of elements such as lead (the "leaded" steels such as 12L13 and 12L14), phosphorus and sulfur (the "rephosphorized, resulfurized" steels such as 1211, 1212, or 1213), sulfur (the "resulfurized only" steels such as 1117, 1118, or 1119), and tellerium, selenium, and bismuth (the "super" free-machining steels).
- Cold finishing.
- Reducing the level of residual stress (usually by a stress-relieving heat treatment).
- Adjusting microstructure to optimize machinability.

Cast iron

Cast irons include many metals having a wide variety of properties. Although cast iron is often considered a simple metal to produce and to specify, the metallurgy of cast iron is more complex than that of steel and most other metals.

Steels and cast irons are both primarily iron with carbon as the main alloying element. Steels contain less than 2 and usually less than 1% carbon; all cast irons contain more than 2% carbon. Two percent is about the maximum carbon content at which iron can solidify as a single-phase alloy with all the carbon solution in austenite. Thus, the cast irons, by definition, solidify as heterogeneous alloys and always have more than one constituent in their microstructure. In addition to carbon, cast irons must also contain silicon, usually from 1 to 3%; thus, they are actually iron-carbon-silicon alloys.

High-carbon content and silicon in cast irons give them excellent castability. Their melting temperatures are appreciably lower than those of steel. Molten iron is more fluid than molten steel and less reactive with molding materials. Formation of lower density graphite during solidification makes production of complex shapes possible. Cast irons, however, do not have sufficient ductility to be rolled or forged.

Machinability ratings of cold-drawn carbon steels

AISI No.	Rating*	AISI No.	Rating*
12L 14†	170	1144	85**
1213	136	1137	72
1215	136	1141	70
1212	100	1018‡	78
1211	94	1045‡	57
1171	91		

*Based on 170 SFPM = 100%.
†Can be treated with tellurium, selenium, or bismuth for further machinability improvement.
‡Lead added to these grades provides major improvement.
**Annealed and cold drawn.

Iron's carbon content is the key to its distinctive properties. The precipitation of carbon (as graphite) during solidification counteracts the normal shrinkage of the solidifying metal, producing sound sections. Graphite also provides excellent machinability (even at wear-resisting hardness levels), damps vibration, and aids lubrication on wearing surfaces (even under borderline lubrication conditions). When most of the carbon remains combined with the iron (as in white iron), the presence of hard iron carbides provides good abrasion resistance.

In some cases, iron microstructure may be all ferrite — the same constituent that makes low-carbon steels soft and easily machined. But the ferrite of iron is different because it contains sufficient dissolved silicon to eliminate the characteristic gummy nature of low-carbon steel. Thus, cast irons containing ferrite do not require sulfur or lead additions in order to be free machining.

Because a casting's size and shape control its solidification rate and strength, design of the casting and the casting process involved must be considered in selecting the type of iron to be specified. While most other metals are specified by a standard chemical analysis, a single analysis of cast iron can produce several entirely different types of iron, depending upon foundry practice and shape and size of the casting, all of which influence cooling rate. Thus, iron is usually specified by mechanical properties. For applications involving high temperatures or requiring specific corrosion resistance, however, some analysis requirements may also be specified.

Patternmaking is no longer a necessary step in manufacturing cast-iron parts. Many gray, ductile, and alloy-iron components can be machined directly from bar that is continuously cast to near-net shape. Not only does this "parts-without-patterns" method save the time and expense of patternmaking, continuous-cast iron also provides a uniformly dense, fine-grained structure, essentially free from porosity, sand, or other inclusions. Keys to the uniform microstructure of the metal are the ferrostatic pressure and the temperature-controlled solidification that are unique to the process.

For each basic type of cast iron, there are a number of grades with widely differing mechanical properties. These variations are caused by differences in

ROLL FORMED SHAPES

One-stop shopping for roll formed products

With over 30 automated lines, Roll Formed Products Company is the nation's largest independent roll former. Our financial strength, an on-site steel service center and extensive engineering capabilities make us the roll forming company to count on when you have a problem to solve.

☑ MATERIALS

Commercial quality, high strength/low alloy, aluminized and galvanized steels, aluminum, brass and copper.

☑ SIZES

Thicknesses from .004"-.250"; finished lengths from a few inches to more than 30 feet.

☑ FINISHES

Zinc, chrome or cadmium plating, dip or spray painting, hot dip galvanizing, strippable plastic coating and in-line embossing.

☑ ...AND MORE

In-house machine shop and engineering department for faster turnaround and tighter controls on quality.

Roll Formed
PRODUCTS COMPANY

A DIVISION OF **Hynes** INDUSTRIES, INC.

3766 Oakwood Avenue
Youngstown, OH 44509-2459
800-321-9257 Outside Ohio
800-321-3616 In Ohio

CUSTOM ROLL FORMING INSTITUTE
CRFI
MEMBER

CALL 1-800-321-9257

© Hynes Industries, Inc. 278-041

Circle 611

the microstructure of the metal that surrounds the graphite (or iron carbides). Two different structures can exist in the same casting. The microstructure of cast iron can be controlled by heat treatment, but once graphite is formed, it remains.

Pearlitic cast-iron grades consist of alternating layers of soft ferrite and hard iron carbide. This laminated structure — called pearlite — is strong and wear resistant, but still quite machinable. As laminations become finer, hardness and strength of the iron increase. Lamination size can be controlled by heat treatment or cooling rate.

Cast irons that are flame hardened, induction hardened, or furnace heated and subsequently oil quenched contain a martensite structure. When tempered, this structure provides machinability with maximum strength and good wear resistance.

Specification methods: ASTM specifications for iron castings are based on a different method than that of the SAE. ASTM specifications designate the properties of the metal to be obtained in an appropriately sized but separately cast test bar, which is poured under the same conditions as are the castings. SAE specifications, on the other hand, require that the microstructure of the casting be appropriate for the specified grade of metal and that the hardness of each casting at a designated location be within the specified range.

Commercially, the ASTM specification is more commonly used for general engineering applications where the strength of the iron necessary in the part has been established. SAE specifications are usually used for large quantities of smaller cast components such as those used in automobiles, and in agricultural and refrigeration equipment. In these cases, the suitability of a particular grade of iron is established, not only on design considerations, but also on actual proof in operation; the purpose of the specification is to ensure a consistent product comparable to those found, by experience, to be satisfactory.

Gray iron: This is a supersaturated solution of carbon in an iron matrix. The excess carbon precipitates out in the form of graphite flakes. Gray iron is specified by a two-digit designation; Class 20, for example, specifies a minimum tensile strength of 20,000 psi. In addition, gray iron is specified by the cross section and minimum strength of a special test bar. Usually, the test-bar cross section matches or is related to a particularly critical section of the casting. This second specification is necessary because the strength of gray iron is highly sensitive to cross section (the smaller the cross section, the faster the cooling rate and the higher the strength).

Impact strength of gray iron is lower than that of most other cast ferrous metals. In addition, gray iron does not have a distinct yield point (as defined by classical formulas) and should not be used when permanent, plastic deformation is preferred to fracture. Another important characteristic of gray iron — particularly for precision machinery — is its ability to damp vibration. Damping capacity is determined principally by the amount and type of graphite flakes. As graphite decreases, damping capacity also decreases.

Gray iron's high compressive strength — three to five times tensile strength — can be used to advantage in certain situations. For example, placing ribs on the compression side of a plate instead of the tension side produces a stronger, lighter component.

Gray irons have excellent wear resistance. Even the softer grades perform well under certain borderline lubrication conditions (as in the upper cylinder walls of internal-combustion engines, for example).

Cast irons – physical properties

Density (lb/in.^{3})	0.25-0.27
Melting temperature (°F)	2,000-2,200
Coefficient of thermal expansion (10^{-6} in./in.-°F)	
Gray (32-212°F)	6
High alloy (32-212°F)	6.5-6.8
Ductile (70-400°F)	6.6
Malleable (70-212°F)	
Ferritic	5.9
Pearlitic	7.5
Thermal conductivity (Btu-ft/hr-ft^2-°F)	28-30 (Malleable, gra 18-20 (Ductile)
Electrical resistivity (Microhm-cm)	14-16 (Malleable) 58, 60 (Gray, ductile

To increase the hardness of gray iron for abrasive-wear applications, alloying elements can be added, special foundry techniques can be used, or the iron can be heat treated. Gray iron can be hardened by flame or induction methods, or the foundry can use a chill in the mold to produce hardened, "white-iron" surfaces.

Typical applications of gray iron include automotive engine blocks, gears, flywheels, brake discs and drums, and machine bases. Gray iron serves well in machinery applications because of its good fatigue resistance.

Ductile iron: Ductile, or nodular, iron contains trace amounts of magnesium which, by reacting with the sulfur and oxygen in the molten iron, precipitates out carbon in the form of small spheres. These spheres improve the stiffness, strength, and shock resistance of ductile iron over gray iron. Different grades are produced by controlling the matrix structure around the graphite, either as-cast or by subsequent heat treatment.

A three-part designation system is used to specify ductile iron. The designation of a typical alloy, 60-40-18, for example, specifies a minimum tensile strength of 60,000 psi, a minimum yield strength of 40,000 psi, and 18% elongation in 2 in.

Ductile iron is used in applications such as crankshafts because of its good

Cast irons – mechanical properties

	DUCTILE (ASTM A48-76)				WHITE	GRAY (ASTM A47-77)			
	80-55-06	60-40-18	100-70-03	120-90-02		20	25	30	40
Yield strength (10^3 psi)	60-75	45-60	75-90	90-125	—	*	*	*	*
Tensile strength (10^3 psi)	90-110	60-80	100-120	120-150	20-50	20-25†	25-30†	30-35†	40-48†
Impact strength, Charpy, (ft-lb)	15-65	60-115	35-50	25-40	3.5-10.0	§	§	§	§
Fatigue endurance limit (10^3 psi)	40	30	44	49	—	10	12.5	14.5	
Creep strength, 0.0001 %/h at 800°F (10^3 psi)	19	14	—	—	—	—	—	—	18
Elongation in 2 in. (%)	6-10	18-25	3-6	2-7	—	<1	<1	<1	<0.8
Modulus of elasticity (10^6 psi)	22-25	22-25	22-25	22-25	—	12	13	15	17

* Yield strength for gray iron is determined by the stress required to produce 0.1% permanent strain, usually about 65 to 80% of tensile strength.

†Tensile strength is highly dependent on section size. §Gray iron is not usually used for impact resistance.

machinability, fatigue strength, and high modulus of elasticity; in heavy-duty gears because of its high yield strength and wear resistance; and in automobile door hinges because of its ductility. Because it contains magnesium as an additional alloying element, ductile iron is stronger and more shock resistant than gray iron. But although ductile iron also has a higher modulus of elasticity, its damping capacity and thermal conductivity are lower than those of gray iron.

By weight, ductile iron castings are more expensive than gray iron. Because they offer higher strength and provide better impact resistance, however, overall part costs may be about the same.

Although it is not a new treatment for ductile iron, austempering has become increasingly known to the engineering community in the past five to ten years. Austempering does not produce the same type of structure as it does in steel because of the high carbon and silicon content of iron. The matrix structure of austempered ductile iron (ADI) sets it apart from other cast irons, making it truly a separate class of engineering materials.

In terms of properties, the ADI matrix almost doubles the strength of conventional ductile iron while retaining its excellent toughness. Like ductile iron, ADI is not a single material; rather, it is a family of materials having various combinations of strength, toughness, and wear resistance. Unfortunately, the absence of a standard specification for the materials has restricted its widespread acceptance and use. To help eliminate this problem, the Ductile Iron Society has proposed property specifications for four grades of austempered ductile iron.

Most current applications for ADI are in transportation equipment — automobiles, trucks, and railroad and military vehicles. The same improved performance and cost savings are expected to make these materials attractive in equipment for other industries such as mining, earthmoving, agriculture, construction, and machine tools.

Proposed specification for four ADI grades

ADI grade	Tensile strength, min (10^3 psi)	Yield strength, min (10^3 psi)	Elongation, min (%)	Hardness (Bhn)	Impact str, unnotched, min (ft-lb)
1	125	85	10	269-331	80
2	150	100	7	302-363	65
3	175	120	4	341-401	45
4	200	140	2	375-461	30

White iron: White iron is produced by "chilling" selected areas of a casting in the mold, which prevents graphitic carbon from precipitating out. Both gray and ductile iron can be chilled to produce a surface of white iron, consisting of iron carbide, or cementite, which is hard and brittle. In castings that are white iron throughout, however, the composition of iron is selected according to part size to ensure that the volume of metal involved can solidify rapidly enough to produce the white-iron structure.

The principal disadvantage of white iron is its brittleness. This can be reduced somewhat by reducing the carbon content or by thoroughly stress relieving the casting to spheroidize the carbides in the matrix. However, these measures increase cost and reduce hardness.

Chills produce castings with white-iron working surfaces and cores that are a tougher and more easily machinable gray or ductile iron. During chilling, that portion of the casting that is to resist wear is cooled by a metal or graphite heat sink (chill) in the mold. When the molten iron contacts the chill, it solidifies so rapidly that the iron and carbon cannot become dissociated.

Chilling should not be confused with heat-treat hardening, which involves an entirely different metallurgical mechanism. White iron, so called because of its very white fracture, can be formed only during solidification. It will not soften except by extended annealing, and it retains its hardness even above 1,000°F.

White irons are used primarily for applications requiring wear and abrasion resistance such as mill liners and shot-blasting nozzles. Other uses include railroad brake shoes, rolling-mill rolls, clay-mixing and brickmaking equipment, and crushers and pulverizers. Generally, plain (unalloyed) white iron costs less than other cast irons.

Compacted graphite iron: Until recently, compacted graphite iron (CGI), also known as vermicular iron, has been primarily a laboratory curiosity. Long known as an intermediate between gray and ductile iron, it possesses many of the favorable properties of each. However, because of process-control difficulties and the necessity of keeping alloy additions within very tight limits, CGI has been extremely difficult to produce successfully on a commercial scale. For example, if the magnesium addition varied by as little as 0.005%, results would be unsatisfactory.

Processing problems have been solved by the joint development efforts of the Foote Mineral Co. and the British Cast Iron Research Association. An alloy-addition package provides the essential alloying ingredients — magnesium, titanium, and rare earths — in exactly the right proportions.

Strength of CGI parts approaches that of ductile cast iron. CGI also offers high thermal conductivity, and its damping capacity is almost as good as that of gray iron; fatigue resistance and ductility are similar to those properties in ductile iron. Machinability is superior to that of ductile iron, and casting yields are high because shrinkage and feeding characteristics are more like gray iron.

The combination of high strength and high thermal conductivity suggests the use of CGI in engine blocks, brake drums, and exhaust manifolds of vehicles. CGI gear plates have replaced alu-

		MALLEABLE**						
		FERRITIC (ASTM A47-77)		PEARLITIC AND MARTENSITIC (ASTM A220-76)				
50	60	32510	35018	40010	45006	50005	70003	90001
*	*	32	35	40	45	50	70	90
50-57†	60-66†	50	53	60	65	70	85	105
§	§	70-90	70-90	22-35	22-35	22-35	22-35	22-35
19	22	24	28	31	—	—	—	—
30	38	—	—	—	—	—	—	—
<0.5	<0.5	10	18	10	6	5	3	1
19	20	25	25	26	26	26	26-28	26-28

**Special grades have tensile strengths up to 135,000 psi and yield strengths up to 110,000 psi.
Strength values apply to nonheat-treated malleable iron. Heat treatments can increase strength.

minum in high-pressure gear pumps because of the iron's ability to maintain dimensional stability at pressures above 1,500 psi.

Malleable iron: Malleable iron is white iron that has been converted by a two-stage heat treatment to a condition having most of its carbon content in the form of irregularly shaped nodules of graphite, called temper carbon. Resulting properties are opposite from those of the white iron from which it is derived. Rather than being hard and brittle, it is malleable and easily machined. Malleable-iron castings generally cost slightly less than ductile-iron castings.

The three basic types of malleable iron are ferritic, pearlitic, and martensitic. Ferritic grades are more machinable and ductile, whereas the pearlitic grades are stronger and harder. Generally, the martensitic grades are grouped with the pearlitic materials; they might be thought of as extensions (at the higher strength end of the range) of pearlitic malleable iron.

LARGER STEEL EXTRUSIONS

Historically, cold-extruded steel parts were limited to just a few pounds. Larger, heavier extrusions were not produced because of press capacity, lack of demand, and because extrusion technology in general did not address the issue of large parts. Now, larger presses, better die design, and improved lubricants are increasing process capabilities to components weighing as much as 100 lb. Within the shape limitations of the extrusion process, there are few sizes, weights, or configurations that cannot be produced today.

In sharp contrast to ferritic malleable iron, whose microstructure is free from combined carbon, pearlitic malleable iron contains from 0.3 to 0.9% carbon in the combined form. Since this constituent can be transformed readily into the hardest form of combined carbon by a simple heating and quenching treatment, pearlitic malleable-iron castings can be selectively hardened. Depth of hardening is controlled by the rate of heat input, time at temperature, and quenching rate. Heat treating can produce surface hardness to about Rockwell C 60.

Carbon in malleable irons helps retain and store lubricants. In extreme-wear service, the pearlitic malleable-iron surface wears away in harmless, micron-size particles, which are less damaging than other types of iron particles. The porous malleable-iron surface traps abrasive debris that accumulates between bearing surfaces. Gall streaks can form on malleable iron but galling does not usually progress.

Malleable-iron castings are often used for heavy-duty bearing surfaces in automobiles, trucks, railroad rolling stock, and farm and construction machinery. Pearlitic grades are highly wear resistant, with hardnesses ranging from 152 to over 300 Bhn. Applications are limited, however, to relatively thin-sectioned castings because of the high shrinkage rate and the need for rapid cooling to produce white iron.

High-alloy irons: High-alloy irons are ductile, gray, or white irons that contain 3 to more than 30% alloy content. Properties by specialized foundries, are significantly different from those of unalloyed irons. These irons are usually specified by chemical composition as well as by various mechanical properties.

White high-alloy irons containing nickel and chromium develop a microstructure with a martensite matrix around primary chromium carbides. This structure provides a high hardness with extreme wear and abrasion resistance. High-chromium irons (typically, about 16%), combine wear and oxidation resistance with toughness. Irons containing from 14 to 24% nickel are austenitic; they provide excellent corrosion resistance for nonmagnetic applications. The 35%-nickel irons have an extremely low coefficient of thermal expansion and are also nonmagnetic and corrosion resistant.

Alloy steel

Steels that contain specified amounts of alloying elements — other than carbon and the commonly accepted amounts of manganese, copper, silicon, sulfur, and phosphorus — are known as alloy steels. Alloying elements are added to change mechanical or physical properties. A steel is considered to be an alloy when the maximum of the range given for the content of alloying elements exceeds one or more of these limits: 1.65% Mn, 0.60% Si, or 0.60% Cu; or when a definite range or minimum amount of any of the following elements is specified or required within the limits recognized for constructional alloy steels: aluminum, chromium (to 3.99%), cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium or other element added to obtain an alloying effect.

Technically, then, tool and stainless steels are alloy steels. In this chapter, however, the term alloy steel is reserved for those steels that contain a modest amount of alloying elements and that usually depend on thermal treatment to develop specific properties. With proper heat treatment, for example, tensile strength of certain alloy steels can be raised from about 55,000 psi to nearly 300,000 psi.

Subdivisions for most steels in this family include "through-hardenable" and "carburizing" grades (plus several specialty grades such as nitriding steels). Through-hardening grades — which are heat treated by quenching and tempering — are used when maximum hardness and strength must extend deep within a part. Carburizing grades are used where a tough core and relatively shallow, hard surface are needed. After a surface-hardening treatment such as carburizing (or nitriding for nitriding alloys), these steels are suitable for parts that must withstand wear as well as high stresses. Cast steels are generally through hardened, not surface treated.

Carbon content and alloying elements influence the overall characteristics of both types of alloy steels. Maximum attainable surface hardness depends primarily on carbon content. Maximum hardness and strength in small sections increase as carbon content increases, up to about 0.7%. However, carbon contents greater than 0.3% can increase the possibility of cracking during quenching or welding. Alloying elements primarily influence hardenability. They also influence other mechanical and fabrication properties including toughness and machinability.

Lead additions (0.15 to 0.35%) substantially improve machinability of alloy steels by high-speed tool steels. For machining with carbide tools, calcium-treated steels are reported to double or triple tool life in addition to improving surface finish.

Few exact rules exist for selecting through-hardening or surface-hardening grades of alloy steels. In most cases, critical parts are field tested to evaluate their performance. Parts with large sections — heavy forgings, for example — are often made from alloy steels that have been vacuum degassed. While in a molten state, these steels are exposed to a vacuum which removes hydrogen and, to a lesser degree, oxygen and nitrogen.

Alloy steels are often specified when high strength is needed in moderate-to-large sections. Whether tensile or yield strength is the basis of design, thermally treated alloy steels generally offer high strength-to-weight ratios. For applications requiring maximum ductility, alloys with low sulfur levels ($< 0.01\%$) can be supplied by producers using ladle-refining techniques.

In general, wear resistance can be improved by increasing the hardness of an alloy, by specifying an alloy with greater carbon content (without increasing hardness), or by both. The surface of a flame-hardened, medium-carbon steel, for example, is likely to have poorer wear resistance than the carbon-rich case of a carburized steel of equal hardness. Exceptions are nitrided parts, which have better wear resistance than would be expected from the carbon content alone.

For any combination of alloy steel and heat treatment, three factors tend to decrease toughness: low service temperature, high loading rates, and stress concentrations or residual stress. The general effects of these three conditions are qualitatively similar, so low-tem-

Cast low-alloy steels—mechanical properties

	ASTM CLASSIFICATION							
	A352	A217	A148	A148	A148	A148	A148	A148
	GRADE							
	LCI Normalized & tempered	WC4 Normalized & tempered	80-50 Normalized & tempered	90-60 Normalized & tempered	105-85 Quenched & tempered	115-95 Quenched & tempered	150-135 Quenched & tempered	160-145 Quenched & tempered
Yield strength (10^3 psi)	35	40	50	60	85	95	135	145
Tensile strength (10^3 psi)	65	70	80	90	105	115	150	160
Impact strength, Charpy (ft-lb)	60	55	48	40	58	45	30	24
Fatigue endurance limit, polished specimen (10^3 psi)	20	23	25	31	34	37	44	48
Elongation in 2 in. (%)	24	20	22	20	17	14	7	6
Hardness, Bhn	—	—	163	187	217	248	311	363

*Alloy steels—carburizing grades**

	AISI TYPE							
	4320		4620		8620		E9310	
	Annealed	Carburized†	Annealed	Carburized†	Annealed	Carburized†	Annealed	Carburized†
Yield strength (10^3 psi)	61	105-107	54	66-67	55	80-83	63	122-123
Tensile strength (10^3 psi)	84	148-152	74	98	77	124-126	119	157-159
Impact strength, Charpy (ft-lb)	—	—	—	64	—	—	65	68-74
Elongation in 2 in. (%)	29	17-18	31	27	31	19-21	17	15-16

*Properties are for 1-in. diam rounds. Creep and fatigue data are not available for those grades—they are rarely subjected to such service.

†Specific values are established by heat treatment times and temperatures. Data apply to core areas only.

SPECIFYING A MALLEABLE IRON

Selecting the proper cast metal for a casting is difficult because the properties of the finished part depend strongly on its size and shape. Most iron specifications apply only to the properties of the metal cast into a standard test bar. Properties of a cast part may vary with cooling rate, cross section, microstructure, and the grade of iron used unlike the properties of wrought metals, which are usually predictable and somewhat independent of final shape.

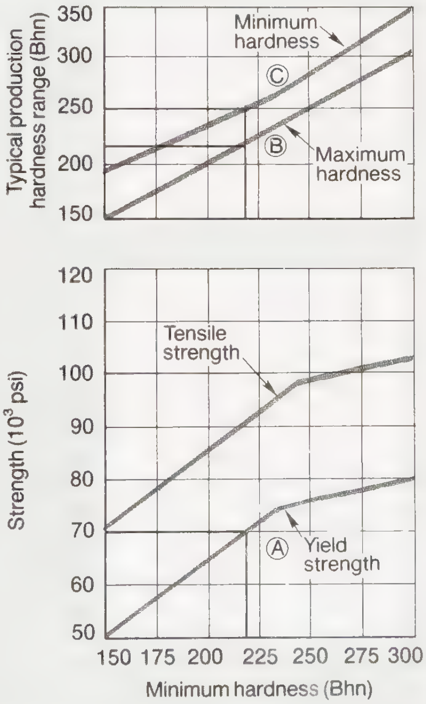
One way to specify a malleable iron is by the grade designations indicated on the accompanying table of properties. However, these designations permit wide variation in chemical composition, heat treatment, and foundry practice in any grade. Such variations may have a strong effect on mechanical properties, especially for the high-strength pearlitic grades.

A more accurate means to specify pearlitic malleable iron is according to Brinell hardness — a predictable, readily controllable property. With the aid of a pair of charts, strength can be related to hardness.

First, strength requirements are established for the metal. Consider, for example, a design that requires a 70,000-psi yield strength. On the lower chart, this corresponds to a minimum hardness of 220 Bhn, point *A*.

For quality-control and production purposes, a hardness range is then determined. The upper curves indicate that an acceptable hardness range is 220-250 Bhn, points *B* and *C*.

In cases where pearlitic malleable iron is specified for wear resistance rather than strength, service conditions usually dictate a minimum hardness requirement. Then only the upper chart is used to establish an acceptable hardness range for the specification.



perature impact tests (to −50°F) are useful for many applications as toughness indicators under various service conditions and temperatures.

Fully hardened-and-tempered, low-carbon (0.10 to 0.30% C) alloy steels have a good combination of strength and toughness, both at room and low temperature. Care must be taken in heat treatment of certain alloy-steel grades, however, because toughness may be decreased substantially by temper brittleness — a form of embrittlement developed by slow cooling through the range of 900 to 600°F, or by holding or tempering in this range.

When liquid quenching is impractical (because of the danger of cracking or distortion, or because of cost), various low-carbon nickel or nickel-molybdenum steels in the normalized-and-tempered condition can be used for low-temperature service.

Wrought alloy steels (and carbon steels) are classified by a series of AISI and SAE numbers that designate composition and alloy type. Letters, which are used in addition to the four-digit designations, include the suffix "H," used for steel produced to specific hardenability limits (which allows wider composition ranges for certain alloying elements), and the prefix "E," which indicates a steel made by the basic electric-furnace method. Other specifications, such as those issued by ASTM, specify minimum properties for critical structural, pressure-vessel, and nuclear applications.

ASTM specifications classify cast alloy steels by relating the steel to the mechanical properties and intended service condition. Chemical analysis is secondary. There are ASTM specifications for general use such as A27 or A148 when mechanical properties are critical. For low-temperature service, A352 or A757 is recommended when toughness is important. For weldability, A216 is specified when fabrication is critical, and for pressure service, A217 or A389 is recommended when a number of properties are important. Still other ASTM alloy steels are available for special applications. Other specifications such as SAE J435 are used for cast steels in automotive applications. A summary of steel-casting specifications is available from the Steel Founders' Society of America, Des Plaines, IL.

Hardness vs approximate strength of alloy steels

Hardness		Tensile strength (10^3 psi)
Rc	Bhm	
	197	93 to 103
	207	98 to 108
	217	103 to 114
	223	106 to 117
22	235	112 to 124
24	248	118 to 131
26	262	124 to 138
29	277	131 to 146
31	293	138 to 154
33	311	146 to 164
34	321	151 to 170
36	341	160 to 180
39	363	171 to 193
40	375	178 to 201
43	401	188 to 222

*These values, for steels fully hardened before being tempered, are most accurate for steels with 0.30% carbon or higher.

Stainless steel

One of the features that characterize stainless steels is a minimum 10.5% chromium content as the principal alloying element. Four major categories of wrought stainless steel, based on metallurgical structure, are austenitic, ferritic, martensitic, and precipitation hardening. Cast stainless-steel grades are generally designated as either heat resistant or corrosion resistant.

Austenitic wrought stainless steel are classified in three groups:

- The AISI 200 series (alloys of iron-chromium-nickel-manganese).
- The AISI 300 series (alloys of iron-chromium-nickel).
- Nitrogen-strengthened alloys.

Carbon content is usually low (0.15% or less), and the alloys contain a minimum of 16% chromium with sufficient nickel and manganese to provide an austenitic structure at all temperatures from the cryogenic region to the melting point of the alloy.

Nitrogen-strengthened austenitic stainless steels are alloys of chromium-manganese-nitrogen; some grades also contain nickel. Yield strengths of these alloys (annealed) are typically 50% higher than those of the nonnitrogen-bearing grades. They are nonmagnetic and most remain so, even after severe cold working.

Like carbon, nitrogen increases the strength of a steel. But unlike carbon, nitrogen does not combine significantly with chromium in a stainless steel. This combination, which forms chromium carbide, reduces the strength and corrosion resistance of an alloy.

Until recently, metallurgists had difficulty adding controlled amounts of nitrogen to an alloy. The development of the argon-oxygen decarburization (AOD) method has made possible strength levels formerly unattainable in conventional annealed stainless alloys.

Austenitic stainless steels are generally used where corrosion resistance and toughness are primary requirements. Typical applications include shafts, pumps, fasteners, and piping in seawater and equipment for processing chemicals, food, and dairy products.

Ferritic wrought alloys (the AISI 400 series) contain from 10.5 to 27% chromium. In addition, the use of argon-oxygen decarburization and vacuum-induction melting has produced several new ferritic grades including

Alloy steels through-hardening grades—mechanical properties

	AISI TYPE					
	1340*		4140, 8740*		4340*	
	Annealed	Normalized, quenched & tempered†	Annealed	Quenched & tempered†	Annealed	Quenched & tempered†
Yield strength (10^3 psi)	63	96-121	60	122-143	68	128-157
Tensile strength (10^3 psi)	102	112-137	95	132-156	108	139-165
Impact strength, Charpy (ft-lb)	52	69	40	68	—	50
Fatigue endurance limit, (10^3 psi)						
Polished specimen, 10 × 10^6 cycles	50	59	—	—	—	—
Creep strength§ (10^3 psi)						
0.0001 %/h at 800°F	22	—	—	44	—	—
Elongation in 2 in. (%)	25	21	25	15-21	22	14-20

*Oil-hardening. †Specific values are established by heat-treament time and temperature. Values are for 1-in. diam rounds. ‡Water-hardening.
§These alloy steels are not often specified for high-temperature applications, so creep data are not always available.

18Cr-2Mo, 26Cr-1Mo, 29Cr-4Mo, and 29Cr-4Mo-2Ni. Low in carbon content, but generally higher in chromium than the martensitic grades, these steels cannot be hardened by heat treating and are only moderately hardened by cold working. Ferritic stainless steels are magnetic and retain their basic microstructure up to the melting point if sufficient Cr and Mo are present. In the annealed condition, strength of these grades is approximately 50% higher than that of carbon steels.

Ferritic stainless steels are typically used where moderate corrosion resistance is required and where toughness is not a major need. They are also used where chloride stress-corrosion cracking may be a problem because they have high resistance to this type of corrosion failure. In heavy sections, achieving sufficient toughness is difficult with the higher-alloyed ferritic grades. Typical applications include automotive trim and exhaust systems and heat-transfer equipment for the chemical and petrochemical industries.

Martensitic steels are also in the AISI 400 series. These wrought, higher-carbon steels contain from 11.5 to 18% chromium and may have small quantities of additional alloying elements. They are magnetic, can be hardened by heat treatment, and have high strength and moderate toughness in the hardened-and-tempered condition. Forming should be done in the annealed condition. Martensitic stainless steels are less resistant to corrosion than the austenitic or ferritic grades. Two types of martensitic steels — 416 and 420F — have been developed specifically for good machinability.

Martensitic stainless steels are used where strength and/or hardness are of primary concern and where the environment is relatively mild from a corrosive standpoint. These alloys are typically used for bearings, molds, cutlery, medical instruments, aircraft structural parts, and turbine components. Type 420 is used increasingly for molds for plastics and for industrial components requiring hardness and corrosion resistance.

Precipitation-hardening stainless steels develop very high strength through a low-temperature heat treatment that does not significantly distort precision parts. Compositions of most precipitation-hardening stainless steels are balanced to produce hardening by an aging treatment that precipitates

HARDENABLE STEELS

Among the elements, the most effective hardenability agent is boron. Where hardenability is a requirement for a carbon steel, domestically available boron can replace the more expensive, imported alloys. For example, in steel of 0.40% carbon content, as little as 0.002% of boron provides the equivalent hardenability of 0.30% manganese, 0.35% molybdenum, 0.50% chromium, or 2% nickel.

Boron was often shunned by steelmakers because of the uncertainty of its reaction. Now, boron can be added in precisely controlled amounts, in conjunction with other elements that protect it from being rendered ineffective by oxygen and nitrogen in the steel.

POROUS METALS

Manufacturers of metal-powder parts have worked hard to increase the density of their products so they can compete with wrought components. In the meantime, engineers have designed to the limitations imposed by the residual porosity in conventionally produced P/M parts. But full density is not required of all metal parts. In fact, many products use the interconnected porosity of P/M structures to advantage. The space between metal particles of selected size and shape provides a continuous network of well-defined holes whose size and distribution can be controlled closely in the processing methods. Most porous P/M parts are made from Type 316L stainless steel, which combines corrosion resistance with availability and competitive cost. These porous parts are used in equipment for a variety of reasons: to filter, separate, or regulate fluid flow; to damp vibration or arrest flame; and to float a web or film in a production system.

AISI designation system for alloy steels

Alloy series	Approximate alloy content (%)
13XX	Mn 1.60-1.90
40XX	Mo 0.20-1.30
41XX	Cr 0.40-1.10; Mo 0.08-0.35
43XX	Ni 1.65-2.00; Cr 0.40-0.90; Mo 0.20-0.30
44XX	Mo 0.35-0.45
46XX	Ni 0.70-2.00; Mo 0.15-0.30
47XX	Ni 0.90-1.20; Cr 0.35-0.55; Mo 0.15-0.40
48XX	Ni 3.25-3.75; Mo 0.20-0.30
50XX	Cr 0.20-0.60
51XX	Cr 0.70-1.15
E51100	C 1.00; Cr 0.90-1.15
E52100	C 1.00; Cr 1.30-1.60
61XX	Cr 0.50-1.10; V 0.10-0.15
86XX	Ni 0.40-0.70; Cr 0.40-0.60; Mo 0.15-0.25
87XX	Ni 0.40-0.70; Cr 0.40-0.60; Mo 0.20-0.30
88XX	Ni 0.40-0.70; Cr 0.40-0.60; Mo 0.30-0.40
92XX	Si 1.20-2.20

6150*		4027‡		4130‡	
Annealed	Quenched & tempered†	Annealed	Quenched & tempered†	Annealed	Quenched & tempered†
59	129-167	47	93-133	52	113-137
96	141-173	75	114-150	81	128-161
26	34	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	
23	14-18	30	16-23	28	14-21

Alloy steels—physical properties

Melting temperature (°F)	2,700-2,800
Coefficient of thermal expansion (10^{-6}in./in.-°F) 70-800°F	7.6-7.7
Thermal conductivity (Btu-ft./hr-ft^2-°F)	17-28*
Density (lb/in.^{3})	0.283-0.284
Electrical resistivity (microhm-cm)	227.1

*Decreases with increasing chromium content.

hard, intermetallic compounds and simultaneously tempers the martensite. The beginning microstructure of PH alloys is austenite or martensite. The austenitic alloys must be thermally treated to transform austenite to martensite before precipitation hardening can be accomplished.

These alloys are used where high strength, moderate corrosion resistance, and good fabricability are required. Typical applications include shafting, high-pressure pumps, aircraft components, high-temper springs, and fasteners.

Cast stainless steels usually have corresponding wrought grades that have similar compositions and proper-

Wrought stainless steels

DESIGNATION AISI or Co.	UNS	Yield strength 70°F (10^3 psi)	Tensile strength (10^3 psi)		Elongation 70°F (%)	Impact strength Izod (ft-lb)		Fatigue endurance limit (10^3 psi)	Creep str 0.0001% at 1,000°F (10^3 psi)	Thermal cond 32-212°F (Btu-ft/h-ft^2-°F)	Coef of thermal exp 32-212°F (10^{-6} in./in.-°F)
			70°F	−320°F		70°F	−320°F				
						AUSTENITIC GRADES					
202	S20200	38	90	220	40	115	120	—	—	9.4	9.7
301	S30100	30	75	275	60	100	110	35	—	9.4	9.4
302	S30200	30	75	220	60	80	110	34	17	9.4	9.6
303/	S30300						125/				
303/Se	S30323	35	85	230	50	80	85(Se)	35	17	9.4	9.6
304	S30400	30	75	220	60	110	115	34	17	9.4	9.6
304L	S30403	25	70	220	60	160^a	110	—	—	—	—
309/	S30900										
309S	S30908	30	75	—	45	110	—	—	16	9.0	8.3
310/	S31000										
310S	S31008	30	75	150	50	110	90	31.5	20	8.2	8.8
316	S31600	30	75	185	60	110	110	38	25	9.4	8.8
316L	S31603	25	70	—	60	—	—	—	—	—	—
317	S31700	35	85	—	50	—	—	—	—	9.4	8.8
317L	S31703	30	80	—	55	—	—	—	—	8.3	9.2
321	S32100	35	90	205	45	110	—	38	—	9.3	9.3
347/	S34700										
348	S34800	30	75	200	50	110	110	39	17	9.3	9.2
AL-GX	NO8366	40	90	—	45	—	—	—	—	7.9	8.5
254 SMO	S31254	44	95	—	35	—	—	—	—	—	9.4
18-9 LW	—	30	78	—	65	—	—	—	—	—	—
						NITROGEN-STRENGTHENED GRADES					
18Cr-2Ni-12Mn	—	60	115	—	55	230^a	—	52	—	—	9.0
21Cr-6Ni-9Mn	S21904	57	100	220	53	240^a	115^a	49	—	8.0	6.3
18-18 Plus	S28200	65	120	228	60	240^a	28^a	50	—	—	—
22Cr-13Ni-5Mn	S20910	65	125	225	45	130^a	50^a	47	—	9.0	9.0
Nitronic 30	—	50	108	—	56	240^a	18^a	—	—	—	9.0
Nitronic 60	S21800	55	105	213	60	240^a	160^a	37	—	—	8.8
						PRECIPITATION-HARDENED GRADES					
15-5 PH	S15500	85-185	120-200	240-260	15-22	16-100	3-28	73-60	—	10.6	6.0
17-4 PH	S17400	85-185	120-200	240-260	15-22	$16\text{-}100^a$	3-28	$73^b\text{-}60^c$	—	10.6	6.0
AM362	S36200	108-182	125-188	—	16-21	6-80	—	95	—	—	—
Custom 450	S45000	117-184	194-196	130-250	13-25	$18\text{-}105^a$	1-36	75-78	—	—	—
Custom 455	S45500	115-235	145-250	—	3-14	$9\text{-}70^a$	$3\text{-}5^a$	—	—	—	—
PH 13-8 Mo	S13800	82-215	130-235	—	12-22	$24^a\text{-}120^a$	$2^a\text{-}30^a$	100	—	—	5.9
17-7 PH	S17700	40-175	130-265	—	2-35	$5\text{-}35^a$	$3\text{-}5^a$	82-110	77^e	9.5	6.0
A286	—	100	150	250	8-50	64^a	57^a	63^d	80	8.2	9.2
						FERRITIC GRADES					
405	S40500	25	60	—	30	20	—	—	8	15.6	6.0
409	S40900	30	55	—	22	—	—	—	—	14.4	6.5
430	S43000	30	65	—	22	35	—	40	8.5	15.1	5.8
446	S44600	40	75	—	20	2	—	47	6.4	12.1	5.8
444^f	S44400	40	60	—	20	—	—	—	—	15.5	5.6
$18Cr\text{-}2Mo^g$	S18200	75-80	80-87	—	14-15	—	—	—	—	—	—
18 SR	—	65	85	—	27	—	—	—	—	—	5.9
Sea-Cure	S44660	75	90	—	32	—	—	—	—	11.4	5.4
Monit	S44635	75	90	—	21	—	—	—	—	9.9	6.1
AL29-4C	S44735	75	90	—	25	—	—	—	—	—	5.2
AL29-4-2	S44800	85	95	—	22	—	—	—	—	—	5.2
						MARTENSITIC GRADES					
403/	S40300										
410	S41000	40	75	—	35	100	—	40	9.2	14.4	5.5
416/	S41600										
416 Se	S41623	40	75	—	30	100	—	40	9.2	14.4	5.5
440A	S44002	60	105	—	20	2	—	40	—	14.0	5.7
440C	S44004	65	110	—	14	2	—	40	—	14.0	5.7

[a] Charpy V-notch. [b] For 10^8 cycles, condition H900, RT [c] At 600°F. [d] For 10^8 cycles aged.

[e] For 15×10^8 cycles, condition RH 950, RT. [f] Stabilized low interstitial (sheet, strip). [g] Free-machining bar.

Note: Unless otherwise indicated, data are for annealed wrought bar. Properties of other mill forms may vary somewhat.

Cast stainless steels

	CA-15[a]	CB-30[b]	CC-50[c]	CE-30[d]	CF-8[e]	CH-20[d]	—	—	CG-6 MMN[h]	CF-10 MnN[h]
Corrosion-resistant grades (ACI designation)	CA-15[a]	CB-30[b]	CC-50[c]	CE-30[d]	CF-8[e]	CH-20[d]	—	—	CG-6 MMN[h]	CF-10 MnN[h]
Heat-resistant grades (ACI designation)[f]	—	—	HC	HE	HF	HH	HT	HX	—	—
Equivalent AISI grades[g] / UNS	410	442	446	312	304	309	330	—	S20910	S21800
Yield strength (10^3 psi)										
CR grades	100	60	65	63	35-40	50	—	—	50	47
HR grades	—	—	75	45	45	50	40	25-40	—	—
Tensile strength (10^3 psi)	115	95	70-110	87-92	75-92	80-88	69-70	56-75	94	96
Impact strength, Charpy, 70°F (ft-lb)	35	2	45	10	70	15	4	—	71	134
Creep strength, 0.0001 %/h (10^3 psi)										
HR grades only, 1,400°F	—	—	1.3	3.5	6	7.0	8.0	6.4	—	—
1,800°F	—	—	0.36	1.0	3.2	2.1	2.0	1.6	—	—
Elongation (%)										
CR grades	30	15	18	18	55	38	—	—	48	54
HR grades	—	—	2	10	35	15-25	10	9	—	—
Modulus of elasticity (10^6 psi)										
CR grades	29	—	29	25	28	28	27	25	28	26
Hardness, Bhn										
CR grades	225	195	210	190	140	190	—	—	210	195
HR grades	—	—	223	200	165	185	180	176	—	—
Melting temperature (°F)	2,700-2,790	2,700-2,750	2,650-2,750	2,600-2,700	2,550-2,600	2,500-2,600	2,400-2,450	2,350	—	—
Coefficient of thermal expansion (10^{-6} in./in.-°F)										
70-212°F	5.5	5.7	5.9	—	9.0	8.3	—	—	9.0	8.8
70-1,000°F	6.4	6.5	6.4	9.6	10.9	9.6	9.8	9.5	10.2	10.0
Thermal conductivity (Btu-ft/h-ft^2-°F)	14.5	12.8	12.6	10.0	9.0	8.2	7.7	11.1	9.0	—
Density (lb/in.^{3})	0.275	0.272 0.274	0.272- 0.277	0.276-	0.280	0.279	0.286	0.294	0.285	0.276
Electrical resistivity, CR grades (microhm-cm)	78.0	76.0	77.0	85.0	76.2	84.0	—	—	82.0	98.2
Magnetic	Yes	Yes	Yes	partially	CF, partially, HF, no	partially	partially	—	slightly	slightly

CR = Corrosion resistant; HR = Heat resistant.

[a] 1,800°F air cooled, 1,200°F tempered.

[b] 1,450°F air cooled.

[c] 1,900°F air cooled.

[d] 2,000°F water quenched.

[e] >1,900°F water quenched.

[f] As cast.

[g] Equivalent wrought grades are given for comparison only; the ACI designations, generally included in ASTM A743 and A297, are used to specify the cast stainless-steel grades.

[h] Annealed

ties. However, there are small but important differences in composition between cast and wrought grades. Stainless-steel castings should be specified by the designations established by the ACI (Alloy Casting Institute), and not by the designation of similar wrought alloys.

Service temperature provides the basis for a distinction between heat-resistant and corrosion-resistant cast grades. The C series of ACI grades designates the corrosion-resistant steels; the H series designates the heat-resistant steels, which can be used for structural applications at service temperatures between 1,200 and 2,200°F. Carbon and nickel contents of the H-series alloys are considerably higher than those of the C series. H-series steels are not immune to corrosion, but they corrode slowly — even when exposed to fuel-combustion products or atmospheres prepared for carburizing and nitriding. C-series grades are used in valve, pumps, and fittings. H-series grades are used for furnace parts and turbine components.

Galling and wear are failure modes that require special attention with stainless steels because these materials serve in many harsh environments. They often operate, for example, at high temperatures, in food-contact applications, and where access is limited. Such restrictions prevent the use of lubricants, leading to metal-to-metal contact — a condition that promotes galling and accelerated wear.

In a sliding-wear situation, a galling failure mode occurs first, followed by dimensional loss due to wear, which is, in turn, usually followed by corrosion. Galling is a severe form of adhesive wear that shows up as torn areas of the metal surface. Galling can be minimized by decreasing contact stresses or by the use of protective surface layers such as lubricants (where acceptable), weld overlays, platings, and nitrided or carburized surface treatments.

Test results from stainless-steel couples (table) indicate the relatively poor galling resistance of austenitic grades and even alloy 17-4 PH, despite its high hardness. Among the standard grades, only AISI 416 and 440C performed well. Good to excellent galling resistance was demonstrated by Armco's Nitronic 32 and 60 alloys (the latter were developed specifically for antigalling service).

Recent research findings prove that adding silicon to a high-manganese, nitrogen-strengthened austenitic stainless alloy produces a wear-resistant stainless steel. Wear and corrosion resistance are still considered unavoidable trade-offs in stainless, but the new formula promises to resist both conditions.

Beating corrosion is the number one reason for choosing stainless. But in cases where parts are difficult to lubricate, most stainless steels cannot resist wear. Under high loads and insufficient lubrication, stainless often sports a type of surface damage known as galling. In critical parts, galling can lead to seizure or freezing, which can shut down machinery.

Designers typically get around galling by using cast alloys or by applying a cobalt facing to stainless parts. Either way, the fixes can be expensive and may pose new problems that accompany the hard-facing process. These include maintaining uniform facing thickness and ensuring proper adhesion between facing and substrate. A new stainless formula aims to sidestep these difficulties by offering an alternative to expensive wear-resistant materials.

In search of a cost-effective alternative, researchers at Carpenter Technology, Reading, PA, looked at elemental effects of silicon, manganese, and nickel on galling resistance of nitrogen-strengthened, austenitic stainless steels. Results of an initial test program determined that silicon was a catalyst for galling resistance, while nickel and manganese were not.

The silicon levels in a recently developed gall-resistant stainless alloy are between 3 and 4%. Silicon levels must remain lower than 5% to maintain the proper metallurgical structure. In addition, too much silicon decreases nitrogen solubility. To maintain strength, higher amounts of costly nickel would need to be added.

Researchers can now define optimum composition limits for a gall-resistant stainless steel. To prove the new steel's validity, properties such as galling, wear, and corrosion are evaluated and compared with commercially available stainless steels. Four alloys, a gall-resistant austenitic alloy called Gall-Tough, another austenitic alloys with higher nickel and manganese content (16Cr-8Ni-4Si-8Mn), and Types 304 and 430 stainless steels are included in the comparison.

Results show the galling threshold for gall-resistant stainless is over 15 times higher than that of conventional stainless steels. In addition, gall-resistant stainless withstands more than twice the stress without galling compared to the 16Cr-8Ni-4Si-8Mn alloy. Yet, the new formula sacrifices only a slight amount of corrosion resistance.

For strength and hardness, both gall-resistant stainless and the 16Cr-8Ni-4Si-8Mn alloy beat Types 304 and 430 alloys. The new alloy also shows a uniquely high ultimate tensile strength, possibly due to martensite formation during tensile testing. Ductility for all four alloys is excellent. These findings indicate that gall-resistant alloys can economically bridge the gap between corrosion, galling, and metal-to-metal wear resistance.

Galling resistance of stainless-steel pairs (unlubricated)

		Threshold stress (10^3 psi) to produce galling									
		AISI type								Nitronic-grades	
AISI type	**Hardness, Bhn**	**410^a**	**416^a**	**430^a**	**$440C^a$**	**303^b**	**304^b**	**316^b**	**$17\text{-}4PH^b$**	**32^b**	**60^b**
410^a	352	3	4	3	3	4	2	2	3	46	50^c
416^a	342	4	13	3	21	9	24	42	2	45	50^c
430^b	159	3	3	2	2	2	2	2	3	8	36
$440C^a$	560	3	21	2	11	5	3	37	3	50^c	50^c
303^b	153	4	9	2	5	2	2	3	3	50^c	50^c
304^b	140	2	24	2	3	2	2	2	2	30	50^c
316^b	150	2	42	2	37	3	2	2	2	3	38
$17\text{-}4PH^b$	415	3	2	3	3	2	2	2	2	50^c	50^c
Nitronic 32^b	235	46	45	8	50^c	50^c	30	21	50^c	30	50^c
Nitronic 60^b	205	50^c	50^c	36	50^c	50^c	50^c	38	50^c	50^c	50^c

Tests were conducted using the crossed-cylinder method on a modified Taber Met-Abrader, on self-mated and dissimilar stainless-steel couples. Data, Armco Inc.

a: Hardened and stress relieved *b:* Annealed *c:* Did not gall

Tool steel

The same properties that qualify tool steels for tools and dies are also used for other parts that require resistance to wear, stability during heat treatment, strength at high temperatures, or toughness. Tool steels are increasingly being used for mechanical parts to reduce size or weight, or to resist wear or high-temperature shock.

Tool steels are metallurgically "clean," high-alloy steels that are melted in relatively small heats in electric furnaces and produced with careful attention to homogeneity. They can be further refined by argon/oxygen decarburization (AOD), vacuum methods, or electroslag refining (ESR). As a result, tool steels are often specified for critical high-strength or wear-resistant applications. Because of their high alloy content, tool steels must be rolled or forged with care to produce satisfactory bar products.

To develop their best properties, tool steels are always heat treated. Because the parts may distort during heat treatment, precision parts should be semi-finished, heat treated, then finished. Severe distortion is most likely to occur during liquid quenching, so an alloy should be selected that provides the needed mechanical properties with the least severe quench.

Tool steels are classified into several broad groups, some of which are further divided into subgroups according to alloy composition, hardenability, or mechanical similarities.

Water-hardening, or carbon, tool steels, designated Type W by AISI, rely solely on carbon content for their useful properties. These steels are available as shallow, medium, or deep hardening, so the specific alloy selected depends on part cross section and required surface and core hardnesses.

Shock-resisting tool steels (Type S) are strong and tough, but they are not as wear resistant as many other tool steels. These steels resist sudden and repeated loadings. Applications include pneumatic tooling parts, chisels, punches, shear blades, bolts, and springs subjected to moderate heat in service.

Cold-work tool steels, which include oil and air-hardening Types O, A, and D, are often more costly but can be quenched less drastically than water-hardening types. Type O steels are oil hardening; Type A and D steels are air hardening (the least severe quench), and are best suited for applications such as machine ways, brick mold liners, and fuel-injector nozzles. The air-hardening types are specified for thin parts or parts with severe changes in cross section — parts that are prone to crack or distort during hardening. Hardened parts from these steels have a high surface hardness; however, these steels should not be specified for service at elevated temperatures.

Hot-work steels (Type H) serve well at elevated temperatures. The tungsten and molybdenum high-alloy hot-work steels are heat and abrasion resistant even at 600 to 1,000°F. But although these alloys do not soften at these high temperatures, they should be preheated before and cooled slowly after service to avoid cracking. The chromium grades of hot-work steels are less expensive than the tungsten and molybdenum grades. One of the chromium grades H11, is used extensively for aircraft parts such as primary airframe structures, cargo-support lugs, catapult hooks, and elevon hinges. Grade H13, which is similar to H11 is usually more readily available from suppliers.

High-speed tool steels — Types T (tungsten alloy) and M (molybdenum alloy) — make good cutting tools be-

Machine Design reprints mean business.

Let us put them to work for you.

Reprints of your advertisements and "Machine Design" articles can be used as:

- ☞ *Direct mail to customers and prospects.*
- ☞ *Sales aids for your people in the field.*
- ☞ *Tools to inform stockholders and employees.*
- ☞ *Training aids for new employees.*
- ☞ *Handouts at trade shows and company meetings.*
- ☞ *New product announcements.*
- ☞ *Follow-ups to ad inquiries.*

For more information about this cost-effective way to get your message out to your customers and staff or to place an order, call Linda L. Fouts, reprints manager, at (216) 696-7000.

MACHINE DESIGN
is a publication of:
Penton Publishing
1100 Superior Avenue
Cleveland, Ohio 44114

A SIMPLE TEST CAN SAVE YOU REAL MONEY.

Get Longer Wear Parts Life In Your Production

Today's production demands the use of Ferro-Tic® metal matrix composite material to extend wear parts life and dramatically reduce costs.

We offer a simple low cost test to show you how Ferro-Tic can improve your specific production applications.

Easily machinable, long-wearing Ferro-Tic naturally withstands heat, cold, corrosion, and stress. Its superior lubricity, hardness, non-abrasive and dampening characteristics offer a smoother, quieter operation with a low coefficient of friction.

With less frequent replacement needed, you save on inventory, labor and production downtime while also improving on production quality and parts uniformity.

Stock items available in 72 hours.

Call today to arrange your test and start saving.

ATI

Alloy Technology
INTERNATIONAL, INC.
169 WESTERN HIGHWAY
WEST NYACK, NY 10994

(914) 358-5900 **(800) 431-1854**

World wide leaders of Operating Technology

Circle 612

Thermal Protection.

Here's a simple way to protect sensitive components from heat... Ultratherm. It's a non-woven fiber mat, bonded between reflective foil layers. It has excellent thermal conductivity, is lightweight and flexible, thin, non-flammable, and corrosion and mildew resistant. Ideal for a wide variety of applications. Write for a sample and literature to Arlon, 199 Amaral St., East Providence, RI 02914, or call (401) 434-2340.

ARLON

Circle 622

cause they resist softening and maintain a sharp cutting edge at high service temperatures. This characteristic is sometimes called "red hardness." These deep-hardening alloys are used for steady, high-load conditions rather than shock loads. Typical applications are pump vanes and parts for heavy-duty strapping machinery.

Other grades, called special-purpose tool steels, include low-cost, Type L, low-alloy steels, often specified for machine parts when wear resistance combined with toughness is important. Carbon-tungsten alloys (Type F) are shallow hardening and wear resistant, but are not suited for high temperatures or for shock service.

Type P mold steels are designed specifically for plastic-molding and zinc die-casting dies. These steels are seldom used for nontooling components.

Many steel mills have formulated their own special-purpose tool-steel alloy. Such alloys may not match a specific AISI designation and must be specified by trade name. Special-purpose tool steels may be superior to the standard grades when used as intended, but they should be specified only after careful evaluation of mechanical properties, heat-treat behavior, and availability in comparison with the standard grades.

Tool steels—mechanical properties

	H11/H13		L2		L6
Condition*	**Annealed**	**Hardened & tempered†**	**Annealed**	**Hardened & tempered**	**Annealed**
Hardening temp (°F)	—	1,850	—	1,575	—
and quench medium	—	Air	—	Oil	—
Annealing temp (F°)	1,600	—	1,425	—	1,425
Tempering temp (F°)	—	1,000	—	400	—
Hardness	96 Rb	54 Rc	96 Rb	54 Rc	93 Rb
Tensile strength (10^3 psi)	100	295	103	290	95
Yield strength (10^3 psi)	53	250	74	260	55
Elongation (%)	25	9	25	5	25
Impact strength, Charpy V-notch (ft-lb)	—	10	—	21	—

*Single temper, oil quench, unless otherwise indicated. †Double temper, air quenched.
§Charpy unnotched. Tests made on longitudinal specimens of small cross-sectional bar stock.

General characteristics of tool steels

AISI type (quench)	**Hardening depth**	**Toughness**	**Wear resistance**	**Decarb resistance**	**Distortion in heat treat**
A2	Deep	Medium	Medium	Medium	Low
A6	Deep	High	Low	Medium	Lowest
A8	Deep	High	Low	Medium	Lowest
D2	Deep	Low	High	Medium	Lowest
D3	Medium	Low	High	Medium	Medium
H11	Deep	Highest	Low	Med, high	Very low
L2 (Water)	Medium	High	Low	High	High
(Oil)	Medium	High	Low	High	Medium
L6	Medium	High	Low	High	Low
S1	Medium	High	Low	Low	Medium
S5	Medium	High	Low	Low	Medium
S7 (Air)	Med, deep	High	Low	Medium	Low
(Oil)	Med, deep	High	Low	Medium	Low
O2	Medium	Medium	Medium	Medium	Medium

HSLA steel

Those steel alloys known as high-strength low-alloy (HSLA) steels provide increased strength-to-weight ratios over conventional low-carbon steels for only a modest price premium. Because HSLA alloys are stronger, they can be used in thinner sections, making them particularly attractive for transportation-equipment components where weight reduction is important. HSLA steels are available in all standard wrought forms — sheet, strip, plate, structural shapes, bar-size shapes, and special shapes.

Typically, HSLA steels are low-carbon steels with up to 1.5% manganese, strengthened by small additions of elements, such as columbium, copper, vanadium or titanium and sometimes by special rolling and cooling techniques. Improved-formability HSLA steels contain additions such as zirconium, calcium, or rare-earth elements for sulfide-inclusion shape control.

Since parts made from HSLA steels can have thinner cross sections than equivalent parts made from low-carbon steel, corrosion of an HSLA steel can significantly reduce strength by decreasing the load-bearing cross section. While additions of elements such as copper, silicon, nickel, chromium, and phosphorus can improve atmospheric corrosion resistance of these alloys, they also increase cost. Galvanizing, zinc-rich coatings, and other rust-preventive finishes can help protect HSLA-steel parts from corrosion.

Grades known as "improved-formability" HSLA steels (sheet-steel grades designated ASTM A715, and plates designated ASTM A656) have yield strengths up to 80,000 psi, yet cost only about 24% more than a typical 34,000-psi plain-carbon steel. Because these alloys must compete with other structural metals such as AISI 1010 steel and aluminum, they must be as inexpensive as possible. However, formulating and rolling a steel that meets this cost requirement is not easy, and the finished product presents a number of trade-offs. For example, the increase in strength from 35,000 to 80,000 psi may be accompanied by a 30 to 40% loss in ductility.

Improved-formability HSLA steels

HSLA steels—mechanical properties

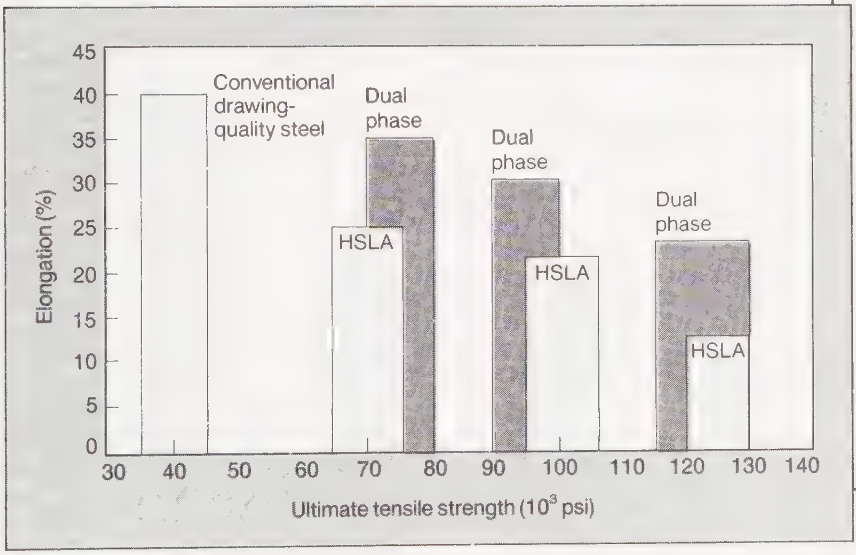
	Semikilled or killed	**Semikilled or killed—improved corrosion resistance**	**Semikilled or killed**	**Inclusion control—Improved formability, killed**
Specifications	ASTM A607 SAE J410C	ASTM A606 Type 4 AISI 050WK 2 & 4 (weathering) SAE J1392	ASTM A607 Grade 50 AISI 050XO SAE J1392	ASTM 715 (Sheet) ASTM A656 (Plate)
Composition	Cb and/or V	(Proprietary) Cu. Cr, C, Mn, Ni, P, & other additions	Cb and/or V	(Proprietary) Cb, Ti, Zr, Si, N, V, & others
Yield strength (10^3 psi)	45	50	50	50
Tensile strength (10^3 psi)	60*	70	65*	60
Cold bending†	1t	1t	1t	0t
Elongation in 2 in. (%)	25	22	22	24§
In 8 in.	19	—	18	20

Adding 0.20% (minimum) Cu to HSLA steels provides approximately two times the atmospheric corrosion resistance of carbon steel. *Reduce by 5,000 psi when lower carbon composition is required.

AISI DESIGNATION										
	P20		S1		S5		S7		A8	
Hardened & tempered	Annealed	Hardened & tempered	Annealed	Hardened & tempered	Annealed	Hardened & tempered	Annealed	Hardened & tempered	Annealed	Hardened & tempered†
1,500	—	1,575	—	1,750	—	1,600	—	1,725	—	1,850
Oil	—	Oil	—	Oil	—	Oil	—	Air	—	Air
—	1,425	—	1,475	—	1,450	—	1,525	—	1,550	—
600	—	400	—	400	—	400	—	400	—	1,000
54 Rc	97 Rb	52 Rc	96 Rb	58 Rc	96 Rb	60 Rc	95 RB	57 Rc	97 Rb	57 Rc
290	100	270	100	300	105	340	93	315	103	340
260	75	205	60	275	64	280	55	210	65	275
4	17	10	24	4	25	5	25	7	24	6
9	—	15	—	184§	—	152§	—	180§	—	5

The producer of the steel should be consulted about heat treatment for specific applications. The heat treatments listed were to develop nominal mechanical properties for hardened and tempered material for test purposes only and may not be suitable for some applications.

These data represent a consensus of the members of AISI Committee of Tool Steel Producers. Because many tool steels have been developed for highly specialized applications, some of their mechanical properties extend beyond the usual range or capacity of conventional test equipment and, thus, beyond the range of repeatability. For example, special tool steels that have been developed for high hardness or wear resistance may measure well beyond conventional hardness scales. Similarly, some tool steels are so impact resistant that they yield meaningless Charpy test results that cannot be reproduced. Valid mechanical test data cannot be reported for many tool steels.



DUAL-PHASE HSLAs

HSLA steel cannot be formed as easily as carbon steels into complex shapes such as automobile body panels and bumpers. But recent years have seen the development of an alternative — dual-phase steels — that offer some of the best of both carbon and conventional HSLA steels. Dual-phase sheet is formable as received, and it strain hardens during forming to yield strengths of 70,000 psi and higher.

Initial developments of these steels started with General Motors, where researchers found that heat treating HSLA steel produced desirable dual-phase properties. Major steel companies were drawn into the development work, and several commercial grades of dual-phase steels are now available. Included are USX's Dual-Phase 80 and LTV's Maxi-Phase 80.

Semikilled or killed	Semikilled or killed	Inclusion control— Improved formability, killed	Semikilled or killed	Semikilled or killed	Sulfide inclusion control— improved formability, killed
ASTM A607	ASTM A607 ASTM A572	ASTM 715 (Sheet)	ASTM A607 ASTM A572	ASTM A607	ASTM 715 Grade 80
SAE J410C	SAE J410C	ASTM A656 (Plate)	SAE J410C	SAE J410C	AISI 080XF SAE J1392
		(Proprietary) Cb, V, Zr, Si, N, Ti, & others	Cb and/or V	Cb and/or V	Cb, V, Ti, and/or rare earths, Zr
55	60	60	65	70	80
70*	75*	70	80*	85*	90
1½t	2t	0t	2½t	3t	1t
20	18	22§	16	14	18
17	16	17	15	14	12

were developed primarily for the automotive industry to replace low-carbon steel parts with thinner cross-section parts for reduced weight without sacrificing strength and dent resistance. Typical passenger-car applications include door-intrusion beams, chassis members, reinforcing and mounting brackets, steering and suspension parts, bumpers, and wheels.

Trucks, construction equipment, off-highway vehicles, mining equipment, and other heavy-duty vehicles use HSLA sheets or plates for chassis components, buckets, grader blades, and structural members outside the body. For these applications, sheets or light-gage plates are specified. Structural forms (alloys from the family of 45,000 to 50,000-psi minimum yield strength HSLA steels) are specified in applications such as offshore oil and gas rigs, single-pole power-transmission towers, railroad cars, and ship construction.

---

†ASTM A370 longitudinal test specimen up to 0.229 in. inclusive. For transverse bending: use values ½ to 2t higher; or to ½t higher for improved-formability grades. §Subtract 2% for thickness 0.097 in. or less.

In equipment such as power cranes, cement mixers, farm machinery, trucks, trailers, and power-transmission towers, HSLA bar, with minimum yield strengths ranging from 50,000 to 70,000 psi is used. Forming, drilling, sawing, and other machining operations on HSLA steels usually require 25 to 30% more power than do structural carbon steels.

Most HSLA alloys have directionally sensitive properties. For some grades, formability and impact strength vary significantly depending on whether the material is tested longitudinally or transversely to the rolled direction. For example, bends parallel to the longitudinal direction are more apt to cause cracking around the outside, tension-bearing surface of the bend. This effect is more pronounced in thick sheets. This directional characteristic is substantially reduced in HSLA steels that have been treated for sulfide shape control.

Ultrahigh-strength steels*—mechanical properties

	TYPICAL DESIGNATIONS			
	Med carbon low-alloys 4140M, 4130M, 4330V, D6AC, 300M, 98BV40, 4340	**Mod 5Cr-Mo-V tool steels** H-11 (mod) H-13 (mod)	**Maraging steels (high nickel)** 18Ni (250) Almar 302 Marvac 736 NiMark	**9Ni-4Co alloys** HP-9-4-30 HP-9-4-20 HP-9-4-45
Yield strength (10^3 psi)	To 250	To 247	245	To 180
Tensile strength (10^3 psi)	To 300	To 311	255	To 280
Impact strength, RT, Charpy (ft-lb)	17	15-22	23	50
Elongation in 2 in. (%)	10	6.6-12	8	10-19

*Heat treated for maximum strength. Design data for specific alloys should be obtained from producers.

Iron-based superalloys

Iron, nickel, and cobalt-based alloys used primarily for high-temperature applications are known as superalloys. The iron-based grades, which are less expensive than cobalt or nickel-based grades, are of three types: alloys that can be strengthened by a martensitic type of transformation, alloys that are austenitic and are strengthened by a sequence of hot and cold working (usually, forging at 2,000 to 2,100°F followed by finishing at 1,200 to 1,600°F), and austenitic alloys strengthened by precipitation hardening.

Some metallurgists consider the last group only as superalloys, the others being categorized as high-temperature, high-strength alloys. In general, the martensitic types are used at temperatures below 1,000°F; the austenitic types, above 1,000°F.

The AISI 600 series of superalloys consists of six subclasses of iron-based alloys:

- **601 through 604:** Martensitic low-alloy steels.
- **610 through 613:** Martensitic secondary hardening steels.
- **614 through 619:** Martensitic chromium steels.
- **630 through 635:** Semi-austenitic and martensitic precipitation-hardening stainless steels.
- **650 through 653:** Austenitic steels strengthened by hot/cold work.
- **660 through 665:** Austenitic superalloys; all grades except alloy 661 are strengthened by second-phase precipitation.

Iron-based superalloys are characterized by high temperature as well as room-temperature strength and resistance to creep, oxidation, corrosion, and wear. Wear resistance increases with carbon content. Maximum wear resistance is obtained in alloys 611, 612, and 613, which are used in high-temperature aircraft bearings and machinery parts subjected to sliding contact. Oxidation resistance increases with chromium content. The martensitic chromium steels, particularly alloy 616, are used for steam-turbine blades.

The superalloys are available in all conventional mill forms — billet, bar, sheet, and forgings — and special shapes are available for most alloys. In general, austenitic alloys are more difficult to machine than martensitic types, which machine best in the annealed condition. Austenitic alloys are usually "gummy" in the solution-treated condition and machine best after being partially aged or fully hardened.

Crack sensitivity makes most of the martensitic steels difficult to weld by conventional methods. These alloys should be annealed or tempered prior to welding; even then, preheating and postheating are recommended. Welding drastically lowers the mechanical properties of alloys that depend on hot/cold work for strength.

All of the martensitic low-alloy steels machine satisfactorily and are readily fabricated by hot working and cold working. The martensitic secondary-hardening and chromium alloys are all hot worked by preheating and hot forging. Austenitic alloys are more difficult to forge than the martensitic grades.

Ferrous P/M

Specifying powder-metallurgy (P/M) parts and their consolidation process used to be a simple process: Design the part, select the metal powders and lubricants that provide the required properties, compact the powders into a briquette, and sinter the briquette into its finished form. Through this procedure, millions of parts have been produced for applications ranging from automobiles to appliances and from business to farm and garden machines.

However, the needs of industries have changed significantly. Removing weight from all products has risen to primary importance. Energy, tooling, and materials costs now figure prominently in parts design, and productivity has emerged as the watchword of the eighties.

With these changes have come changes in powder-metallurgy technology. Through the many manufacturing processes, improvements have been made in the powders themselves — improvements such as lower levels of inclusions and higher compressibility. In addition to conventional iron and steel metals, the list of available powders has been expanded to include new classes of tool steel, as well as materials such as cermets and alloys of titanium, nickel, and aluminum.

Accompanying these developments has been the growth of new consolidation technologies. As a result, design engineers need current information on which P/M technologies are viable, cost effective, and production effective, and which have potentially wide application.

Although powder metallurgy is used to fabricate parts from just about any metal, the most commonly used metals are the iron-based alloys. Low-density iron P/M parts (5.6 to 6.0 gm/cm^3), with a typical tensile strength of 16,000 psi, are usually used in bearing applications. Copper is commonly added to improve both strength and bearing

Iron-based superalloys—mechanical properties

	MARTENSITIC							AUSTENITIC				
	Martensitic low alloy		Secondary hardening			Martensitic chromium		Semiaustenitic		Hot/cold worked		Precip str
AISI grade	601	604	610	613	616	619	633	635	650	653	660	665
Typical designation	17-22A	Chromalloy	H-11	M-50	422	Lapelloy	AM350	Stainless W	16-25-G	17-24 CuMo	A-286	W-545
Yield strength (10^3 psi)												
70°F	100	95-108	100-240	335	125-175	85-220	60-175	215-290	50-100	40-90	95	123-142
1,000°F	54	85	140	250	126	85	108	37-50	33	29	88	120
Tensile strength (10^3 psi)												
70°F	120	125-138	135-310	410	150-240	125-250	160-205	220-225	110-140	86-112	146	176-187
1,000°F	77	110	180	309	170	95	160	75-80	90	65	131	154
Impact strength, Charpy 70°F (ft-lb)	—	—	10-32	—	10-38	—	14	4-106	15	8-26	41-60	—
Fatigue endurance limit (10^3 psi)	—	—	130	—	90-110	—	70-100	54-96	—	—	—	—
Creep strength (10^3 psi) 0.0001%/h at 1,000°F	—	—	—	—	—	—	—	—	26	10	—	—
Elongation in 2 in. (%)												
70°F	30	7	3-17	2	16-19	10-20	12-38	1-5	20-45	30-45	25	19
1,000°F	29	—	11	6	16	15	9	47-58	58	37	19	13
Modulus of elasticity (10^6 psi)	30.8	31.7	30.5	29.5	29.0	30.0	29.4	30.2	28.5	28.0	28.8	28.4
Rupture strength (10^6 psi) 100 h at 1,000°F	49	75	95-115	—	58	65	103	32	78	48	100	120

properties. Alloy-steel powders are sometimes hot forged to high or nearly theoretical density to form parts with improved mechanical properties which, when heat treated, may have tensile strengths to 170,000 psi. Powder forging (P/F) is now established as a serious contender for parts formerly made as wrought forgings or machined from mill forms. New vendors with sophisticated automated equipment are increasing the overall P/F capacity as well as contributing to better quality of output.

Iron P/M or sintered iron-copper alloy strength can be varied by adjusting density, carbon content (up to 15%), or all three to satisfy specific design requirements. Each variable can be adjusted by the vendor to satisfy tolerances, mechanical properties, and other requirements of the part being made.

Low-density P/M parts are used in bearing applications because they provide porosity for oil storage. Impregnating sintered-metal bearings with oil usually eliminates the need for relubrication.

For higher strength needs, alloyed (frequently prealloyed Ni/Mo/Fe) iron, compacted to a higher density, is used. When carbon or other alloying elements are mixed with the iron powders and densities exceed 6.2 gm/cm^3, the parts are considered to be steel rather than iron. As carbon content is increased up to 1%, the strength of steel P/M parts increases, just as the strength of wrought steel increases with higher carbon content.

Additional applications can be accommodated by sealing the pores in iron P/M parts. The sealing materials used are copper, polyesters, and anaerobics; each requires a different processing system to impregnate the parts. Impregnation of sintered P/M parts is done for any of several reasons:

- To serve in pressure-tight applications.
- To improve surface finish. (Impregnated parts are platable.)
- To improve machinability.
- To improve corrosion resistance.

Although high precision has been achieved in P/M parts for many years, their application was once restricted because of mechanical property limitations. Now, however, mechanical properties can be increased in steel P/M parts by hot forging in closed dies. Properties of P/M parts forged to 100% theoretical density in production conditions are claimed to be equal, and sometimes superior, to those of wrought steels of similar composition.

Relatively complex carbon or low-alloy steel parts required in large quantities are ideal candidates for P/M forgings. Automakers have been among the first to use these full-dense, precision-forged components in transmissions, accessory mechanisms, and engines.

Adding carbon enables steel P/M parts to be heat treated to increase hardness, toughness, wear resistance, and strength. The addition of alloying elements in the iron-powder mix further enhances the properties of heat-treated steel P/M parts.

Ferrous P/M parts containing 0.3% or higher combined carbon can be quench hardened for increased strength and wear resistance. Surface hardness values of 500 to 650 Knoop, which are file hard, can be obtained by quenching.

In addition, ferrous parts can be carburized by standard means other than liquid salts. Low-density parts carburize throughout while high-density parts develop a distinct carburized case. Very-high-density parts respond favorably to fused salt carbonitriding, but density must be high enough to prevent salt absorption into the pore structure. Tempering for stress relief after quenching is also possible, although oil vapors generated by quench oil in the pore structure of P/M parts must be vented or dispersed. ■

Technical assistance for the **Ferrous metals** section was provided by: **Advanced Metalworking Practices Inc.,** Kokomo, IN, Ferrous P/M; **AL Tech Specialty Steel Corp.,** Dunkirk, NY, Tool steel, Superalloys; **American Iron and Steel Institute,** Washington, DC, Tool steel, Stainless steel; **Armco Inc.,** Middletown, OH, Stainless steel, HSLA steel; **Carpenter Technology Corp.,** Reading, PA, Tool steel, Stainless steel, Superalloys; **Climax Molybdenum Co.,** Ann Arbor, MI, Stainless steel; **Hoeganaes Corp.,** Riverton, NJ, Ferrous PM; **Iron Castings Society,** Des Plaines, IL, Introduction to ferrous metallurgy, Cast iron; **Steel Founders' Society of America,** Des Plaines, IL, Carbon steel, Stainless steel, Alloy steel; **Uddeholm Corp.,** Totawa, NJ, Tool steel.

Additional engineering materials

Today's design engineer's "toolbox" includes carbon, ceramics, glass, and noise-control materials to complement traditional construction materials.

Remarkable developments in structural materials technologies have taken place in the last 30 years. Formerly brittle ceramics are being transformed into materials tough enough to withstand engine environments. Carbon bearings do the job in places where lubrication is difficult. These and other old-but-new materials are appearing in a variety of applications, ranging from cutting tools and engine pistons to tennis racquets.

Carbon

Manufactured carbon comprises a large family of materials, available in hundreds of grades and shapes including plates, rods, tubes, and rings. Many of the grades have been developed for specific applications.

The parts are made from mixtures of coke and graphite powder bonded with carbon. The proportions and types of these materials are selected to obtain the lubricity and wear resistance required in the finished component. The carbon binder is derived from coal-tar pitch or synthetic resins chosen for their high coking yield. The mixture is then formed by compression molding or warm extrusion.

The formed shape is fired at temperatures as high as 1,300°C in an oxygen-free environment, which converts the binder to carbon. The resulting baked carbon part contains interconnected pores, which are usually impregnated with resins, fused salts, glasses, or molten metals. Impregnation enhances physical properties and can also reduce rubbing friction and wear rates.

During the firing operation, carbon parts shrink by 5 to 15%. Shrinkage of a given grade is predictable, however, and small parts having dimensions within a 1% tolerance band can be produced without machining. Some shapes are graphitized by a second baking to at least 2,600°F.

Most manufactured carbon parts require some machining to produce required tolerances. Only the hardest carbide or diamond-tipped tools can be used for some grades. Because of this, the larger U.S. carbon producers offer machining service for producing parts to customer specifications.

Properties: Manufactured carbon offers a number of desirable characteristics for engineered parts. It is

- A good conductor of heat and electricity.
- Self-lubricating; it slides on metals without galling or welding.
- Corrosion resistant; it is unaffected by solvents, caustics, and most acids.

In addition, carbon does not soften or melt. It is stronger at 2,760°C (5,000°F) than at room temperature. Like ceramics, however, manufactured carbon is brittle. Its strain-to-failure ratio in tension ranges from 0.05 to 1.0%, depending on grade and temperature. Due to its texture, however, its strength is not sensitive to surface scratches or nicks. Its fatigue resistance exceeds that of most metals.

Manufactured carbon parts are unaffected by reducing gases but are slowly attacked by oxygen at elevated temperature. Weight loss rates in air reach 0.1%/h at temperatures ranging from 315 to 700°C, depending on grade and surface area. Manufactured carbon can also be weakened by strong oxidizing liquids such as hot, concentrated nitric acid.

Properties of carbon-graphite composites are largely controlled by the fillers and binders used, forming methods, baking temperature, and impregnant, if used. Fillers such as coke can produce harder, more abrasive carbons than can graphite fillers. Very fine filler grains lead to stiffer, stronger carbons. Fine-grain mixes, however, usually require processing by compression molding rather than extrusion.

Applications: The most common use of manufactured carbon is as sliding elements in mechanical devices. It is used as the primary rubbing face in most mechanical seals. Used as a brush, it transfers electrical current to the rotating commutator on small electric motors. Carbon vanes, piston rings, or cylinder liners are used in most small air pumps and drink-dispenser pumps. Carbon is also used for pistons in chemical-metering pumps and for metering valves in gasoline pumps. All these applications require the carbon to slide on metal with a coefficient of friction below 0.2 and a wear rate below 0.001 in. per million inches rubbed.

Bearings are another significant application area for manufactured carbon. In many cases, characteristics of the carbon bearing are tailored to satisfy a wide range of requirements. This is done by impregnating the porous, as-baked or as-graphitized carbon with various materials — for example, resin, babbitt, copper, or glass — or by combining impregnation with chemical conversion of the carbon surface (to hard silicon carbide).

These self-lubricating materials are particularly suited for environments containing dust or lint, repeated steam cleaning, solvents, or corrosive fluids, low or high temperatures, high static loads, or hard vacuums. Some of these conditions require impregnants in the carbon material. Other applications using manufactured-carbon bearings are those inaccessible for lubrication or where product contamination (from lubricants) cannot be tolerated.

Engineering ceramics

Engineered ceramic parts serve in many structural applications at extremely high temperatures. Other than thermal stability, ceramics offer high strength, light weight, and corrosion resistance. In addition, raw materials needed for making ceramics are abundant.

The nature of the bond between ceramic particles helps differentiate the engineering ceramics from most other ceramics, such as porcelain or refractory brick. Most particles within an engineering ceramic are self-bonded; that is, joined at grain boundaries by the same energy-equilibrium mechanism that bonds metal grains together. In contrast, most nonengineering ceramic particles are joined by a so-called ceramic bond, which is a weaker, mechanical linking or interlocking of particles. Generally, impurities in nonengineering ceramics prevent the particles from self-bonding.

The modulus of rupture (MOR), also called flexural strength, is usually used

Now you can take your designs to the extremes.

Introducing PORON S2000 Silicone Foam for temperature-extreme applications.

With PORON S2000, Rogers has added silicone foam technology to its family of urethanes to provide you with a greater range of solutions to your design problems.

PORON S2000 has a finer cell structure to deliver better thickness control, more flexibility, and greater tear resistance than other silicone foams. PORON S2000 can withstand temperature extremes as well: up to **400° F** (204°C) and down to **–40°F** (–40°C) while remaining flexible – even during vibration. It's inherently **flame retardant** and has **low compression set**, so it's perfect for automotive and aerospace applications. Best of all, it's backed by the quality of service and delivery that's made Rogers famous.

Call a Rogers PORON specialist today at (203) 774-9605, or circle the response card for more information and a free PORON S2000 Silicone sample kit.

Technology for tomorrow built on TQC today.

ROGERS

Rogers Corporation PORON Materials Division
Box 158, East Woodstock CT 06244
203-774-9605 FAX 203-928-7843
PORON is a registered trademark of Rogers Corporation

Circle 613

The PORON family portrait.

PORON® cellular urethanes come in different shapes, sizes, and colors.

PORON solves gasketing, shock, and vibration problems.
The PORON family of engineering microcellular urethanes offers the broadest selection of material solutions for gasketing, shock and vibration energy absorption problems. No matter how it's used, PORON increases design quality and performance across-the-board and across a wide temperature range. It's compatible with most adhesives, offers excellent resistance to compression set, and can be die-cut, slit, milled, or laminated.

There's a PORON For You

Whether you're designing gaskets and seals, shock isolaters, cushion pads, motor mounts, vibration mounts, springs, spacers, RF shielding, tape substrates, athletic padding, or printed circuit board cushions, there's a PORON for you. The PORON family of cellular urethanes is available in:

- **Twelve Different Formulations**
  Including;
  Antimicrobial,
  High Temperature, to 105°C
  High Compressive Modulus to 55psi
  Low Compressive Modulus to 6psi
- **Four Standard Densities**
  15, 20, 25, 30 lbs/ft^3
- **Eleven Standard Colors**
  With custom colors available
- **A Range of Thicknesses**
  From 0.031" to 0.625"

Technology for tomorrow built on TQC today.

ROGERS
Rogers Corporation PORON Materials Division
Box 158 East Woodstock, CT 06244
203-774-9605 FAX: 203-928-7843

Call a PORON specialist at 203-774-9605, or circle the response card for more information and a free PORON test kit.

PORON is a registered trademark of Rogers Corporation

Circle 614

Low Cost Laminates for Static Flex Applications are Just Around the Bend.

BEND/flex laminates may save costs compared to polyimide film circuitry.

Design your static flex circuits with BEND/flex® bendable circuit laminate material from Rogers and you may realize substantial savings in material and fabrication costs. Without sacrificing design flexibility or performance. In some applications, BEND/flex laminates may actually increase overall product performance. For example, BEND/flex circuits allow auto insertion of components without the use of rigidizers.

The future belongs to designers who can think small and save big. BEND/flex laminates can help make that happen.

For all the ways BEND/flex laminates can improve your design options write for a free test kit.

Technology for tomorrow built on TQC today.

ROGERS

Rogers Corporation
Composite Materials Division
One Technology Drive
Rogers, CT 06263
203 774-9605 FAX 203 774-1973

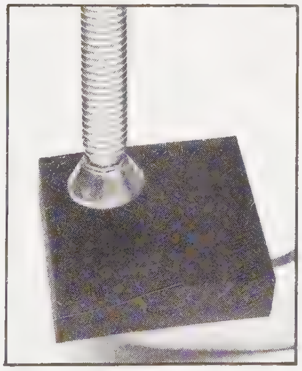
U.L. 94VO flame class rating.
BEND/flex is a registered trademark of Rogers Corporation. Also available through Mektron Europe, Ghent Belgium and Rogers Inoac Corp., Nagoya, Japan.

Circle 615

SPEEDY RECOVERY

PORON RECOVERS THICKNESS BEST

Sponge rubber: C-clamp leaves permanent impression



PORON: Impression disappears in seconds

Put it to the test. Free. We'll send you a simple test kit which dramatically demonstrates how PORON cellular urethane recovers from prolonged compression. How it absorbs shock. And why it's an ideal seal, gasket or cushioning material. Contact our PORON product specialist today at **(203) 774-9605.** We think you'll be impressed.

ROGERS

Rogers Corporation
PORON Materials Division
Box 158, East Woodstock, CT 06244
Tel. 203 774-9605

Circle 616

Now you can take your designs to the extremes.

Rogers' PORON® S2000 Cellular Silicone Foam for temperature-extreme applications.

- Withstands temperatures up to 400° F (204° C), down to – 40°F (– 40°C) and remains flexible, even during vibration
- Inherently flame retardant
- Low compression set
- Finer cell structure for better thickness control, greater tear resistance, more flexibility
- Perfect for automotive and aerospace applications

Circle the response card for more information and a free PORON S2000 Silicone sample kit.

Technology for tomorrow built on TQC today

ROGERS

Rogers Corporation PORON Materials Division
Box 158 East Woodstock, CT 06244
203-774-9605 FAX: 203-928-7843
PORON is a registered trademark of Rogers Corporation.

Circle 617

to measure the strength of ceramics for critical, high-strength applications. In the MOR test, the sample — usually a rectangular plate — is supported near the ends, and a bending load is applied at its center. The load is increased until the sample ruptures. Two loading conditions are commonly used: In a three-point test, the load is applied at one point midway between the two supports; a more uniform four-point version calls for a load applied at two points equidistant from the supports.

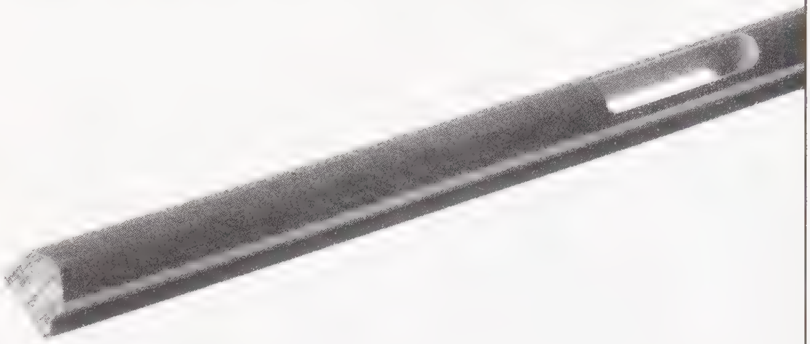
Published property values for ceramic materials can be misleading. While the data may be scientifically valid, they only represent a particular measurement method on a particular piece of material at a particular time. Without a complete material characterization and the use of standard measurement techniques, the values may have little applicability. Thermal-conductivity values, for example, are highly dependent on microscopic and macroscopic characteristics, structure, orientation, and other material-related characteristics. The nature and magnitude of porosity in a ceramic specimen, for instance, can affect thermal conductivity by a factor of two or three.

The inherent brittleness of ceramics makes special considerations necessary in designing with these materials. In ductile metals, localized stresses that exceed the yield point are usually relieved by local plastic deformation that redistributes the stress into a wider area, preventing fracture. Ceramics, however, have no such yield point; they fail when localized stresses exceed material strength. Typically, elastic behavior is linear right up to the fracture point. Moreover, they usually have high moduli of elasticity, which results in fracture at relatively small strains.

Several companies are conducting research programs aimed at increasing the ductility, or toughness, of ceramic materials. The directions that appear most promising involve transformation toughening and reinforcing the matrix with a dispersed phase such as fibers or whiskers — for example, silicon-nitride fibers in a silicon-carbide structure.

Sensitivity to process-related defects, in combination with a lack of ductility, intensifies the need for dependable nondestructive evaluation (NDE) methods for engineering ceramics. Successful use of these materials for demanding applications requires accurate, reliable information to improve processing technology, eliminate critical defects, and increase yield. Another requirement is a solid understanding of appropriate NDE signals, leading to realistic accept/reject crite-

ENVEX® POLYIMIDE
High Temperature Performance at a Cool Price.



- Capable of continuous use operation up to 550°F (288°C)
- Low cost with short lead times
- Available in stock shapes and finished parts
- Superior strength and dimensional stability

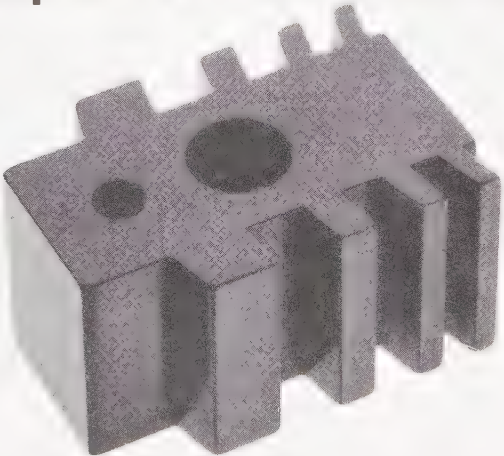
Call or write for a free brochure.

ENVEX® is a registered trademark for Rogers Polyimides

ROGERS
Rogers Corporation, Composite Materials Division
One Technology Drive, Rogers, CT 06263, 203-774-9605, FAX: 203-774-1973

Circle 618

ENVEX® POLYIMIDE
High Temperature Performance at a Cool Price.



- Capable of continuous use operation up to 550°F (288°C)
- Low cost with short lead times
- Available in stock shapes and finished parts
- Superior strength and dimensional stability

Call or write for a free brochure.

ENVEX® is a registered trademark for Rogers Polyimides

ROGERS
Rogers Corporation, Composite Materials Division
One Technology Drive, Rogers, CT 06263, 203-774-9605, FAX: 203-774-1973

Circle 619

ria for ceramic components. New evaluation methods now being used promise both improved flaw-detection capability and the reliable detection of smaller defects.

Ceramic oxides: Although most metals form at least one chemical compound with oxygen, only a few oxides are useful as the principal constituent of a ceramic. And of these, only three are used in their fairly pure form as engineering ceramics: alumina, beryllia, and zirconia.

The natural alloying element in the alumina system is silica. However, aluminas can be alloyed with chromium (which forms a second phase with the alumina and strengthens the ceramic) or with various oxides of silicon, magnesium, or calcium.

Aluminas serve well at temperatures as high as 3,500°F provided they are not exposed to thermal shock, impact, or highly corrosive atmospheres. Above 3,700°F, strength of alumina drops. Consequently, many applications are in steady-state, high-temperature environments, but not where abrupt temperature changes would cause failure from thermal shock. Aluminas have good creep resistance up to about 1,500°F, above which other ceramics perform better. In addition, aluminas are susceptible to corrosion from strong acids, steam, and sodium.

Beryllia ceramics are efficient heat dissipaters and excellent electrical insulators. They are used in electrical and electronics applications, such as microelectric substrates, transistor bases, and resistor cores. Beryllia has excellent thermal shock resistance (some grades can withstand 1,500°F/sec changes), a very low coefficient of thermal expansion, and a high thermal conductivity. It is expensive, however, and is an allergen to which some persons are sensitive.

Zirconia is used primarily for its extreme inertness to most metals. Zirconia ceramics retain strength nearly up to their melting point — well over 4,000°F, the highest of all ceramics. Applications for fused or sintered zirconia include crucibles and furnace bricks.

Transformation-toughened zirconia ceramics are among the strongest and toughest ceramics made. These materials are of three main types: Mg-PSZ (zirconia partially stabilized with magnesium oxide, Y-TZP (Yttria stabilized tetragonal zirconia polycrystals), and ZTA (zirconia-toughened alumina).

Applications of Mg-PSZ ceramics are principally in low and moderate-temperature abrasive and corrosive environments — pump and valve parts, seals, bushings, impellers, and knife blades. Y-TZP ceramics (stronger than Mg-PSZ but less flaw tolerant) are used for pump and valve components requiring wear and corrosion resistance in room-temperature service. ZTA ceramics, which have lower density, better thermal shock resistance, and lower cost than the other two, are used in transportation equipment where they need to withstand corrosion, erosion, abrasion, and thermal shock.

Many engineering ceramics have multioxide crystalline phases. An especially useful one is cordierite (magnesia-alumina-silicate), which is used in cellular ceramic form as a support for a washcoat and catalyst in catalytic converters in automobile emissions systems. Its low coefficient of thermal expansion is a necessary property for resistance to thermal fracture.

Glass ceramics: Composed of several oxides that form complex, multiphase microstructures, glass ceramics are called that because they are formed from molten glass and subsequently crystallized by heat treatment. Glass ceramics do not have the strength-limiting porosity of conventional sintered ceramics. Properties can be tailored by control of the crystalline structure in the host glass matrix. Major applications are cooking vessels, tableware, smooth cooktops, and various technical products such as radomes.

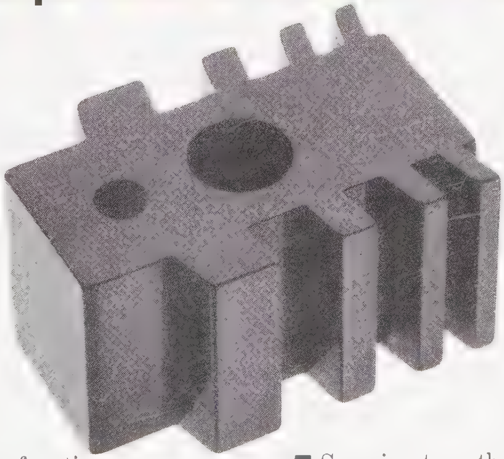
The three common glass ceramics, lithium-aluminum-silicate (LAS, or beta spodumene), magnesium-aluminum-silicate (MAS, or cordierite), and aluminum-silicate (AS, or aluminous keatite), are stable at high temperatures, have near-zero coefficients of thermal expansion, and resist various forms of high-temperature corrosion, especially oxidation. LAS and AS have essentially no measurable thermal expansion up to 800°F. The high silica content of LAS is responsible for the low thermal expansion, but the silica also decreases strength. LAS is attacked by sulfur and sodium.

MAS is stronger and more corrosion resistant than LAS. A multiphased version of this material, MAS with aluminum titanate, has good corrosion resistance up to 2,000°F.

AS, produced by leaching lithium out of LAS particles prior to forming, is both strong and corrosion resistant. It has been used, for example, in an experimental rotating regenerator for a turbine engine.

A proprietary ceramic (Macor, of Corning Glass Works), called machinable glass ceramic (MGC), is about as

ENVEX POLYIMIDE
High Temperature Performance at a Cool Price.



- Capable of continuous use operation up to 550°F (288°C)
- Low cost with short lead times
- Available in stock shapes and finished parts
- Superior strength and dimensional stability

Call or write for a free brochure.

ENVEX® is a registered trademark for Rogers Polyimides

ROGERS
Rogers Corporation, Composite Materials Division
One Technology Drive, Rogers, CT 06263, 203-774-9605, FAX: 203-774-1973

Circle 620

strong as alumina. It also has many of the high-temperature and electrical properties of the glass ceramics. The main virtue of this material is that it can be machined with conventional tools. It is available in bars, or it can be rough formed, then finish machined. Machined parts do not require firing.

A similar glass ceramic is based on chemically machinable glass which, in its initial state, is photosensitive. After the glass is sensitized by light to create a pattern, it is chemically machined (etched) to form the desired article. The part can then be used in its glassy state, or it can be fired to convert it to a glass ceramic. This material/process combination is used where precision tolerances are required and where a close match to thermal expansion characteristics of metals is needed. Typical applications are sliders for disk-memory read/write heads, wire guides for dot-matrix printers, cell sheets for gas-discharge displays, and substrates for thick-film and thin-film metallization.

Another ceramiclike material, glass-bonded mica, the moldable/machinable ceramic, is also called a "ceramoplastic" because its properties are similar to those of ceramics, but it can be machined and molded like a plastic material. A glass/mica mixture is pressed into a preform, heated to make the glass flow, then transfer or compression molded to the desired shape. The material is also formed into sheets and rods that can be machined with conventional carbide tooling. No firing is required after machining.

The thermal-expansion coefficient of glass-bonded mica is close to that of many metals. This property, along with its extremely low shrinkage during molding, allows metal inserts to be molded into the material and also ensures close dimensional tolerances. Molding tolerances as close as ±0.0005 in. can be held. Continuous service temperatures for glass-bonded mica range from cryogenic to 700 or 1,300°F depending upon material grade.

Carbides and nitrides: Several metal carbides and nitrides qualify as engineering ceramics. Most commonly used are boron carbide and nitride, silicon carbide and nitride, and aluminum nitride.

Boron carbide is noted for its very high hardness and low density — unusual qualities for a brittle ceramic — which qualify this ceramic for lightweight, bulletproof armor plate. The material has the best abrasion resistance of any ceramic, so it is also specified for pressure-blasting nozzles and similar high-wear applications. A limitation of boron carbide is its low strength at high temperatures.

Despite their higher cost, silicon carbide (SiC), aluminum nitride (AlN), and boron nitride (BN) are challenging alumina, particularly for the more critical applications. BN, for example, has a high dielectric strength and near-zero thermal expansion in some ranges.

Silicon carbide and silicon nitride are the high-temperature, high-strength "superstars" of the engineering ceramics. These are the strongest structural ceramics for high-temperature oxidation-resistant service. However, SiN and SiC do not easily self-bond. Consequently, many processing variations have been devised to fabricate parts from these materials, creating a number of trade-offs in cost, fabricability, and properties. Either ceramic can be consolidated by hot pressing. Under the combination of high temperature and pressure — with, in some cases, additives that act as bond-forming catalysts — fully dense material can be formed.

The hot-pressed ceramic is extremely strong and tough at high temperatures, but the manufacturing process is limited to simple shapes, bars, or billets. Complex parts made by hot pressing must be machined to shape — a slow and costly process of ultrasonic machining, EDM (if possible), or diamond grinding.

On the other hand, SiN and SiC particles can be bonded without pressure by a number of processes, variously called reaction bonding, recrystallization (for silicon carbide), or reaction sintering. With these processes, "green" parts can be dry or isostatically pressed, extruded, slip-cast, or, in some cases, formed by conventional plastic molding techniques such as injection molding, then sintered. Complex shapes, close to finished size, can be produced by these techniques, but the ceramic is only about 80% as dense as the hot-pressed counterpart and has lower strength and poorer thermal shock resistance.

Silicon carbide — either hot pressed or reaction bonded — is not as strong as silicon nitride up to about 2,600°F, silicon-nitride grain boundaries soften, or creep, and strength drops. Above 2,600°F, silicon carbide is the stronger ceramic. At 2,400°F, however, strength of hot-pressed ceramics nearly equals that of reaction-bonded ceramics.

Hot-pressed SiC is harder and more difficult to EDM that SiN, which has lower thermal expansion and better thermal shock resistance than SiC. Electrical resistivity of silicon carbide is low at low frequencies and high at high frequencies — an unusual characteristic that qualifies this material as a semiconductor.

Glass

Glass is an amorphous solid made by fusing silica with a basic oxide. Although its atoms never arrange themselves in a crystalline order, atomic spacing in glass is tight. Glass is characterized by transparency, hardness at atmospheric temperatures, and excellent resistance to weathering and most chemicals except hydrofluoric acid.

Most glass is based on the silicate system and is made from three major constituents: silica (SiO), lime ($CaCO_3$), and sodium carbonate ($NaCO_3$). Various oxides are added to tailor the properties of glass to meet specific requirements.

Nonsilicate-system glasses, which account for only about 5% of all glass produced (excluding glass ceramics, described in the chapter, *Engineering ceramics*), include phosphate glasses (that resist HF acid), rare-earth borate glasses (for high refractive index), heat-absorbing glasses (made with FeO), and systems based on oxides of aluminum, vanadium, germanium, and other metals. Nearly all glasses can be categorized into one of six basic types, based on chemical composition. Within each type, except for fused silica, are several distinct compositions.

Soda-lime glass, the most common type, is the glass of bottles, windows, light bulbs and drinking glasses. Its composition is similar to that of the earliest man-made glass — a mixture of the oxides of silicon, calcium, and sodium. Approximately 90% of all glass melted today is soda-lime (or simply "lime" as it is commonly called). This inexpensive glass is readily fabricated to a wide variety of shapes. Resistance to high temperatures and to sudden temperature changes is poor, and resistance to attack by chemicals is only fair.

Borosilicate glass, the oldest type of glass to have appreciable resistance to thermal shock and higher temperatures, also has excellent resistance to chemical attack. In this glass structure, the first to carry the Pyrex trademark, some of the SiO_2 is replaced by boric oxide.

Borosilicate glass has a low coefficient of thermal expansion and is, thus, suited for telescope mirrors and other precision parts. Also, because this glass can withstand thermal shock, it is used for oven and laboratory ware, headlamp lenses, and boiler gage glasses. Most borosilicate glasses have better resistance to acids than do soda-lime

Introducing

ISOLOSS®

High strength,
high performance materials
for mechanical energy control

E·A·R
Specialty Composites

Circle 621

ISOLOSS elastomers
Diverse applications in demanding environments

E-A-R's new ISOLOSS polyurethane elastomer material family is specially created to help simplify the mechanical energy control design process for OEM products.

Proprietary ISOLOSS materials combine superlative damping performance and excellent mechanical strength with impressive environmental resistance properties and a wide service temperature range for high performance in diverse applications.

Proprietary ISOLOSS polyurethane formulations are available in solid sheet and foam configurations, in a range of thicknesses and densities, as precision die-cut parts, and as standard and custom molded products.

From constrained layer damping systems in complex shipboard applications to highly energy absorbent seat padding in military aircraft, from hard-working bumpers in material handling systems to precise shock mounts for sensitive computer disk drives — ISOLOSS materials perform.

Damped isolation materials

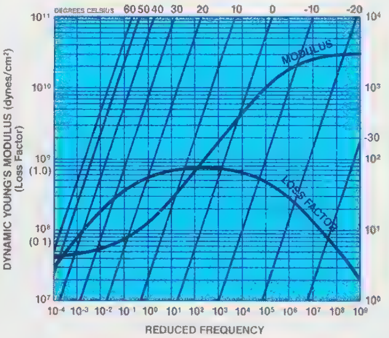
ISOLOSS HD ELASTOMERS

ISOLOSS HD formulations are moldable, solid, crosslinked thermoset polyurethane elastomers that combine excellent physical strength and durability with exceptional damping performance and uniform modulus throughout a broad temperature range.

In sheets and as die-cut parts, ISOLOSS HD materials are ideal for gasketing, sealing and constrained layer damping applications. ISOLOSS HD materials are UL-listed for flame resistance and provide optimal vibration damping performance from −20°C to 40°C, exhibiting uniform stiffness and a consistent dynamic Young's modulus to 90°C.

With excellent compression set resistance, ISOLOSS HD materials also are highly abrasion resistant and withstand degradation from exposure to fluids and ultraviolet radiation.

REDUCED FREQUENCY NOMOGRAM
ISOLOSS HD MATERIALS



ISOLOSS VL MATERIALS

Low modulus ISOLOSS VL materials provide good damping performance, consistent low durometer and stable material properties across a wide temperature range.

Moldable ISOLOSS VL materials exhibit peak damping from −20°C to 60°C, and maintain their properties down to −40°C. Compared with other materials of similar modulus, ISOLOSS VL sheets and die-cut parts exhibit good tensile and tear strength, as well as creep and compression set resistance.

ISOLOSS MOLDED PARTS

Available in a range of moldable, metal-bondable, proprietary formulations, standard and custom-molded ISOLOSS parts afford the right combinations of performance and physical properties for virtually any application requiring shock protection, noise control and vibration isolation. ISOLOSS molded parts are used extensively in computer disk drives, appliances, and medical, office and laboratory equipment. Configurations include grommets, metal-bonded isolators, bumpers, crash stops, bushings, mounts, inertial dampers, gaskets and seals.

Parts molded from ISOLOSS HD formulations exhibit high damping performance, and superior strength, durability and stability. HD parts have excellent environmental resistance properties and provide consistent performance throughout a wide service temperature range.

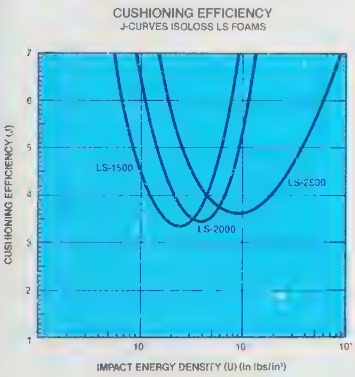
Molded ISOLOSS VL products combine inherent softness with good damping capabilities, low modulus, creep resistance and stability over a broad temperature range. They are ideal for applications ranging from compact isolation systems to subway car bumpe

Energy absorption and cushioning materials

ISOLOSS LS CELLULAR URETHANES

ISOLOSS LS cellular urethane materials are fine-celled, high density foams that offer low compression set, high strength, abrasion resistance and dimensional stability for numerous OEM applications, including gasketing, low-load isolation and shock-protective padding.

Inherently soft, yet mechanically tough, ISOLOSS LS foams combine excellent shock control and cushioning properties, effectively resisting compression set and stress relaxation, and providing high tensile and tear strength and excellent abrasion resistance. They withstand fluid, chemical and ultraviolet exposure, and offer broad temperature range capabilities as well.



Available in sheets or roll form, in a range of thicknesses and densities, ISOLOSS LS foams can be fabricated with various facings and combinations of pressure sensitive adhesives. They also are easily and cleanly die cut.

CONFOR™ ERGONOMIC FOAMS

CONFOR ergonomic foams are medium-density, open-celled urethanes that offer a balanced combination of temperature-softening behavior, impact absorption and a slow rate of return from deflection, for use in a wide range of cushioning, shock absorption and gasketing applications.

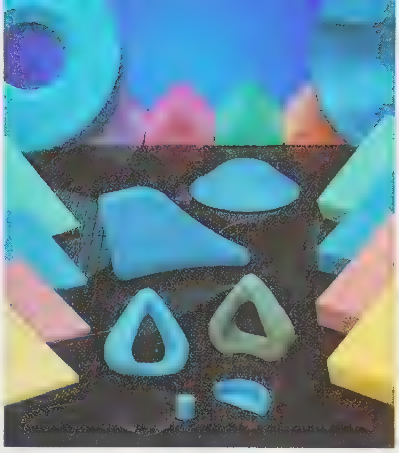
In contact with warmth, the foams soften and conform, providing uniform pressure distribution and fluid-like support. Surfaces exposed to lower temperatures, however, remain relatively stiff and supportive. Formulated to absorb up to 97 percent of shock energy, without bottoming out, CONFOR foams are breathable and able to dissipate moisture.

In sheets, buns or as die cut parts, moldable CONFOR materials are available in a range of stiffnesses, and can be combined with adhesive backings, film and fabric facings, and protective coatings.

ISOLOSS MOLDED FOAMS

Moldable ISOLOSS foam formulations combine the excellent physical and performance properties of the ISOLOSS family with the versatility and economy of cast-urethane molding technology.

Proprietary ISOLOSS foam formulations are available in a continuum of densities and stiffnesses, as well as with varying levels of resilience and physical strength, for a wide variety of padding, cushioning and sealing applications, including seat cushions, medical padding, instrument seals, case linings and shoe inserts. ISOLOSS molded foams perform in a broad range of temperatures and can be customized to meet specific modulus, strength, durometer, color and surface texture requirements.

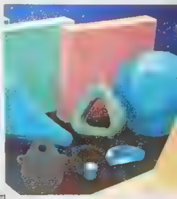


VISCOLAS® MATERIALS

VISCOLAS moldable viscoelastic urethanes combine high shock absorption properties with extremely low modulus and excellent resistance to compression set. Their physical toughness and ability to dissipate impact energy make these materials well-suited to a variety of physical protection and ergonomic uses, such as shoe inserts, work gloves and tool grips.

Upon impact, VISCOLAS products displace shock energy laterally, spreading the force evenly for maximum dissipation over a broad range of vibration frequencies and varying temperature profiles.

VISCOLAS formulations are available in standard sheets, in a range of durometers, and can be molded into custom configurations. They also combine readily with a variety of fabrics, film facings and adhesives.



Circle 621

E-A-R...total capabilities for OEM mechanical energy control

The ISOLOSS polyurethane elastomer family is the latest material development from E-A-R Specialty Composites, a division of Cabot Safety Corporation.

For more than 20 years, Indianapolis-based E-A-R has been providing advanced energy control materials and problem-solving technology to OEM markets. E-A-R manufactures the most complete line of noise, vibration, shock and motion control products available from a single source. And we are the only such producer to offer all the basic materials tools — damping, isolation, barrier, absorption and cushioning materials — for today's complex OEM design requirements.

Our proprietary materials expertise begins with the growing ISODAMP® family of damping and damped-isolation molding thermoplastics, extends to include the versatile TUFCOTE® line of acoustical foams, barriers and composites, and proceeds with the formulation of high performance specialty materials for the electronics, marine, defense and aerospace industries. And now, it includes our new ISOLOSS family of polyurethane elastomers.

Our complete product line, advanced materials technology and extensive problem-solving experience mean that we can engineer and deliver cost-efficient, on-target solutions tailored to fit the requirements of virtually any mechanical energy control application.

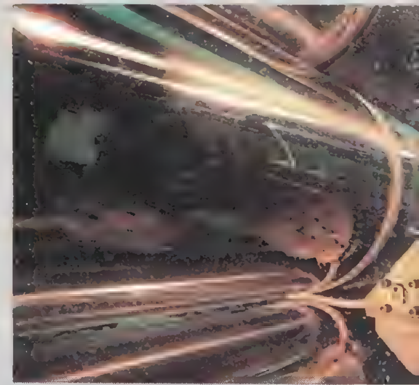
We market our products worldwide through a network of technically oriented sales representatives, whose in-depth field experience and knowledge of OEM product and service requirements constitute a primary source of mechanical energy control expertise for discriminating design engineers in many OEM markets.

Customers rely on E-A-R products and service for consistently high quality and performance. Our facilities in Indianapolis and in Newark, Delaware, encompass nearly 300,000 square feet of combined capacity, housing complete processing, manufacturing and fabrication operations, as well as state-of-the-art laboratories for OEM product testing, R&D, materials development and quality assurance.

E-A-R is uniquely capable of solving the total range of mechanical energy control problems facing today's manufacturers. For authoritative, practical assistance with your product design requirements, E-A-R is all you need to know for noise, vibration, shock and motion control.

...state-of-the-art technology for product development, materials testing an quality assurance.

...customized solutions through precise OEM product analysis and prototype design.



...technologically advanced processing equipment that affords consistently on-spec production.

...large-scale manufacturing operations ensuring economy, versatility an flexibility.

E-A-R
Specialty Composites

Division, Cabot Safety Corporation

7911 Zionsville Road
Indianapolis, Indiana 46268
(317) 872-1111
Fax: (317) 872-0618

Delaware Industrial Park
Newark, Delaware 19713
(302) 738-6800
Fax: (302) 738-6811

©1991 Cabot Safety Corporation. ISOLOSS®, CONFOR™, VISCOLAS®, ISODAMP® and TUFCOTE® are trademarks of Cabot Safety Corporation. ISOLOSS HD elastomers are manufactured under U.S. Patent No. 5,010,133.

Circle 621

glasses, but poor resistance to alkalis. Glass fibers used in reinforcing plastic compounds are a modified borosilicate glass.

Lead-alkali glass, or lead glass, contains lead monoxide, PbO, to increase its index of refraction. This glass is a better electrical insulator than soda-lime or borosilicate glasses. Lead glass is used for optical applications such as prisms and lenses and as a shield against atomic radiation. It is easy to work and is well suited for slow, manual operations. Because of its natural luster, lead glass is used for fine crystal tableware. Like lime glass, lead glass has poor resistance to high temperatures and to thermal shock.

Glass

	Soda-lime	Boro-silicate	Lead glass	Alumino-silicate	Fused silica	96% silica
Thermal shock resistance, 6 ×6-in. plates 1/8-in. thick, annealed (°F)	149	320	115-150	257-275	—	—
Modulus of elasticity (10^6 psi)	10.2	9.0	8.5-9.0	12.5-12.7	10.5	9.8
Softening temperature (°F)	1,285	1,510	932-1,160	1,666-1,679	2,876	2,786
Coefficient of thermal expansion 32-572°F (10^{-7} in./in.-°F)	47-52	18-19	50-70	23-26	3.1	4.2
Thermal conductivity (Btu-in./h-ft^2-°F)	7.0	7.8	5.2	9.0	9.3	10.0
Density (lb/in.^{3})	0.089	0.081	0.103-0.126	0.091-0.095	0.079	0.079
Electrical resistivity at 70°F ($\log_{10}$ ohm-cm)*	12.4	14	17	17	17	17
Refractive index†	1.525	1.473	1.540-1.560	1.530-1.547	1.459	1.458

*Extrapolated from higher-temperature determinations. †Clear grades.

Aluminosilicate glass (in which some alumina, Al_2O_3, replaces silica) is another thermal-shock-resisting glass similar to borosilicate but able to withstand higher operating temperatures. These glasses also resist chemical attack and are good electrical insulators. Aluminosilicate glasses are suited for high-performance applications such as high-temperature thermometers, space-vehicle windows, and ignition tubes. Coated with an electrically conductive film, they are used as resistors in critical electronic circuitry. Aluminosilicates cost about three times more than borosilicates and are appreciably more difficult to fabricate.

96% silica glass is a highly heat-resistant glass made from borosilicate glass by a proprietary (Corning Glass Works) process. This glass can be formed more readily and into more shapes than can fused silica. Its properties are so close to those of fused silica that it is sometimes used as a substitute in optical components and spacecraft windows, where it must withstand the heat of reentry into the earth's atmosphere. It is also used as a heat-resisting coating such as on the exterior of NASA's space-shuttle vehicles. Other uses include laboratory ware and lighting components such as arc tubes in halogen lamps.

Fused silica is the only one of the six categories that contains a single composition. This glass consists simply of silica (silicon dioxide) in the noncrystalline, or amorphous, state. Fused silica, most expensive of all glasses, offers the maximum resistance to thermal shock as well as the highest permissible operating temperature (900°C for extended periods, to 1,200°C for short periods). It also has maximum transmission in the ultraviolet range and the highest resistance to chemical attack of any glass. Fused silica is used in applications where requirements are extremely strict, such as mirror blanks for astronomical telescopes, ultrasonic delay lines, optical communications waveguides, and crucibles for growing crystals. Fabrication of fused silica is difficult, and the number of available shapes is, therefore, sharply limited.

These six types of glass can be grouped in three pairs. Soda-lime and lead-alkali are termed soft glasses because they soften or fuse at relatively low temperatures. Borosilicate and aluminosilicate are called hard glasses because they soften or fuse at relatively higher temperatures. And 96% silica and fused silica are the hardest of all.

The oldest of the glasses is soda-lime, which was known some 4,000 years ago. Lead-alkali was developed in 1676, borosilicate in 1912, aluminosilicate in 1936, 96% silica in 1939, and fused silica in 1952.

Today, many glass products are made from composites, made up of several glasses of differing composition. High-strength tableware is made of a sandwich of a low-expansion glass and a high-expansion glass core. Optical communications fibers (waveguides) are drawn from a boule built up from glass having a controlled variation in composition. Aerospace-vehicle windows are composed of multiple panes of glass, each pane with a unique property; the outermost panes are heat resistant, the innermost panes are mechanically strong.

Light-sensitive glasses, although not considered a basic type, are available in three grades. Photochromic glass darkens when exposed to ultraviolet radiation and fades when the ultraviolet stimulus is removed or when the glass is heated. Some photochromic compositions remain darkened for a week or longer. Others fade within a few minutes after ultraviolet is removed. A chief use for the faster-fading compositions is in eyeglass lenses that automatically darken and fade when exposed to or removed from sunlight.

Photosensitive glass also responds to light, but in a different manner from photochromic glass. When exposed to ultraviolet energy and then heated, photosensitive glass changes from clear to opal. When the UV exposure is made through a mask, the pattern of the mask is reproduced in the glass. The image developed is permanent and will not fade, as would a similar image in a photochromic glass. The exposed, opalized photosensitive glass is much more soluble in hydrofluidic acid than the unexposed glass. Immersion in this acid produces shapes, depressions, or holes by etching away of those exposed and developed areas.

Photochromatic glasses are full-color photosensitive glasses. Developed in 1978 by Corning Glass Works laboratories, their characteristics imply applications such as information storage, decorative objects, windows, or other transparencies, and containers. Photochromic glasses have true color permanence.

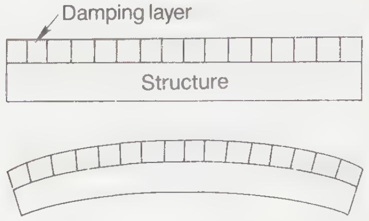
Noise-control materials

In order to control noise, designers must first determine where the noise source or sources are how much each is contributing to the overall level, and their frequency signatures. This can be done with a combination of instruments: a Type I ⅓-octave band sound-level meter, a sound intensity analyzer, and if there may be significant structural-borne noise, by model analysis of various components.

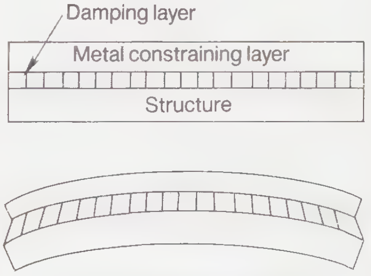
Once the sources have been identified and quantified, they can be ranked by how each contributes to the overall noise level. This is most important because if lower-level noise contributors are silenced first, this will not reduce the overall level. For example, when the exhaust is louder than the air intake on a gas or diesel engine, reducing the air intake noise gains little noise reduction

Comparing absorption materials

Density/ materials	Acoustical properties (Absorption)	Hydrolytic stability	Ultra-violet and ozone resistance	Flammability	Useful smoke generation	Temperature range (°F)
2 lb Polyester	E	VG/F	G/F	HF-1	High	−50 to + 225
4 lb Polyester	E	VG/F	G/F	HF-1	High	−50 to + 225
6 lb Polyester	E	VG/F	G/F	HF-2	High	−50 to + 225
2 lb Polyester	VG	E	G/F	HF-1	High	−50 to + 225
4 lb Polyester	E/VG	E	G/F	HF-2	High	−50 to + 225
.7 lb Methane	E/VG	E	E	V-0	0	−50 to + 450
.6 lb Polymide	E	G/F	VG	V-0	0	−50 to + 400
1 lb Fiberglass	F	G/F	VG	V-0	V-Low	−50 to + 375
2 lb Fiberglass	G	G	VG	V-0	V-Low	−50 to + 375
3 lb Fiberglass	VG	VG	VG	V-0	Low	−50 to + 375
4 lb Fiberglass	E	VG	VG	V-0	Low	−50 to + 375



Free-layer damping



Constrained-layer damping

until a properly sized muffler is installed.

When trying to control noise in any type machinery, designers generally end up employing some, if not all, four elements of noise control. These are absorption, barrier, dampers, and gasketing materials.

Absorption material: A good candidate will "soak up" airborne sound-energy waves by changing the wave energy into heat as it passes through the absorption medium. Absorption materials are generally either fibrous or cellular. Common fibrous material are fiberglass, mineral wool, and ceramic. These are applied as blanket or semi-rigid sheets which can be cut to shape. Generally, they are film faced or bagged to prevent the fibers from being dislodged and causing problems in air-handling systems or rotating machines when bearings or other components could prematurely wear out if they became contaminated.

Newly developed melamine and polyimide cellular materials offer significant advantages over traditional urethanes in many respects. The melamine required only 40% the weight of a comparable urethane, costs 30% more, and has no smoke or toxic by-product of combustion. The polyimide foam has similar characteristics to the melamine but costs 10 to 12 times as much, and is not as hydrolytically stable.

Film facing will reduce overall absorption at higher frequencies. This may be a problem if most of the noise energy generated is also at these frequencies.

Barriers: There are two types of barriers — those that already exist (walls, cabinets, enclosures, etc.) and supplemental barriers. Supplemental barriers are those which you add if the existing enclosure wall is not thick enough. In this case, mass is the key to controlling noise. The mass law for homogeneous materials gives a rough approximation of the amount of noise that can be reduced given a specific materials mass.

However, the same reduction cannot be achieved at all frequencies. There is less attenuation (noise reduction) in the lower frequencies than the highs for a given mass, in this case, 9.6 oz/ft^2, or lead. The mass law predicts only 6 dB

NOISE CONTROL BASICS

All noise control systems make use of at least one of the following material types:

- Barriers, such as enclosures, flexible plastic curtains, or walls. Typically solid materials, barriers act as acoustical reflectors, interrupting the path of sound waves with their mass. A barrier's ability to block sound increases proportionally with its weight per unit area.
- Absorption materials, such as fiberglass batts or blankets, acoustical tiles, or acoustical foams. Often backed by a barrier material, the absorber reduces energy in a sound wave by converting mechanical motion of the air particles into low-grade heat. This action prevents sound buildup in enclosed spaces and reduces the strength of reflected noise. Thick materials absorb low frequencies better, while thin materials absorb high frequencies more efficiently.
- Vibration isolators, such as engine and pump mounts, plastic or rubber-based bushings and grommets, and steel spring equipment supports. Isolators connect two structures, but allow relative motion between them under dynamic loading conditions. The required amount of motion depends chiefly on the range of frequencies over which the isolator must operate. Transmissibility T_R is a common measure of isolator performance, with lower T_R values indicating better performance. T_R equals vibration output of a system divided by the magnitude of vibration input to the system.
- Damping materials, such as plastic sheets, mastic solutions, and adhesive films. Amount of damping is based on base material and thickness, temperature and frequency characteristics, ratio of damping material thickness to base material thickness, and percent surface area covered. Performance of a damping system is measured by the system loss factor, which determines expected noise reduction.

The first two categories, barriers and absorption materials, deal with airborne noise, or noise already present in the environment. The last two items, vibration isolators and damping materials, deal with structureborne noise, or vibration. This noise appears as airborne noise after being radiated by a structure, unless it is contained or dissipated. Containment involves isolating the vibration, while dissipation results from damping.

In general, effective noise control requires both absorption and barriers to reduce airborne noise, and both isolation and damping for structureborne noise. Because sound is mechanical energy, it always finds a path from its source to the outside world. Noise control block these paths and eliminates the energy wherever possible.

additional attenuation if the weight is doubled. But separating the two sheets of lead with a ½-in. decoupling layer of open-cell urethane foam produces a significantly greater increase particularly above 500 Hz. Bonding a single layer of 10 oz/ft^2 to a 20-gage steel panel would result in even greater noise reduction.

These figures all assume "perfect" walls in which there are no openings. This is not very practical in most everyday applications. When openings are created for pipes, wires, air, and products to enter and exit, noise is let out. The amount of noise reduction expected from a perfect wall or enclosure diminishes drastically in the real world. As the opening size increases as a percentage of the total enclosure area, the actual noise reduction decreases.

For example, with a transmission loss potential of 20 dB or greater and 10% opening, designers can never get more than 10-dB noise reduction. However, this can be drastically increased by sealing around wires, pipes, and air ducts. In addition, noise reduction is increased by providing absorption-lined tunnels for materials that have to be fed into and out of the enclosure. These "supplemented" barriers are easy to fabricate and install either mechanically or with preapplied pressure-sensitive adhesive.

Damping: All materials have a natural frequency. When they are excited by some source at this natural frequency, they will vibrate. This causes the air surrounding the material to vibrate and produce noise. Sometimes referred to as "oil can" or "drum head" phenomenon, this type of noise can be controlled by damping. Properly applied damping materials will only work if the metal or plastic to which they are applied is vibrating at or near their resonant frequency. If a mechanically driven plate is vibrating, damping will not stop it. And it should be noted that all damping materials are temperature sensitive, so they must be selected both for their temperature range and the operating temperature of the material to which they are applied.

Damping materials work to reduce the vibration in the material to which they are applied by dissipating the vibrating energy as heat, rather than radiating it as acoustic energy or noise. Damping materials are termed "viscoelastic," having both elastic and viscous properties. Essentially, the material is stretched when it is bonded to a vibrating surface. There are two types of damping material, homogeneous or free-layer damping and constrained layer. Homogeneous/free-layer materi-

A practical handbook to help you design today's sophisticated machines —

STANDARD HANDBOOK OF MACHINE DESIGN

By Joseph E. Shigley and Charles R. Mischke

1,632 pages, 929 illustrations, **$124.50**

The entire subject of machine design is presented with emphasis on solving problems that arise daily in engineering design. The wide range of new materials, new components, new processes, and new analytical tools that have brought great changes in the way machines are designed have been covered to permit the design of machines in the future to meet more rigorous standards of reliability, safety, lighter weight, greater speed, and compactness. Use of computer-aided design methods as well as other machine-computation facilities are integrated throughout the handbook and presented in such a manner that future developments in computer hardware and software will not render the contents of the handbook obsolete.

47 GIANT SECTIONS fully cover every aspect of machine design.

To order your copy, complete the coupon below and mail to: Penton Education Division, 1100 Superior Avenue, Cleveland, Ohio 44114 or, for faster service, call 800-321-7003 (In Ohio, call 216-696-7000).

ORDER FORM

Please send me ____ copy(s) of STANDARD HANDBOOK OF MACHINE DESIGN. I understand that I can review it for 15 days and, if not satisfied, return it for full refund or credit.

☐ My payment is enclosed for postage-free shipment in the U.S. and Canada.

☐ Bill my company and include shipping and handling charges. Company purchase order required.

☐ Charge my: ☐ MasterCard ☐ Visa ☐ American Express Card

Account No. ______________________ Exp. Date __________

Name ______________________

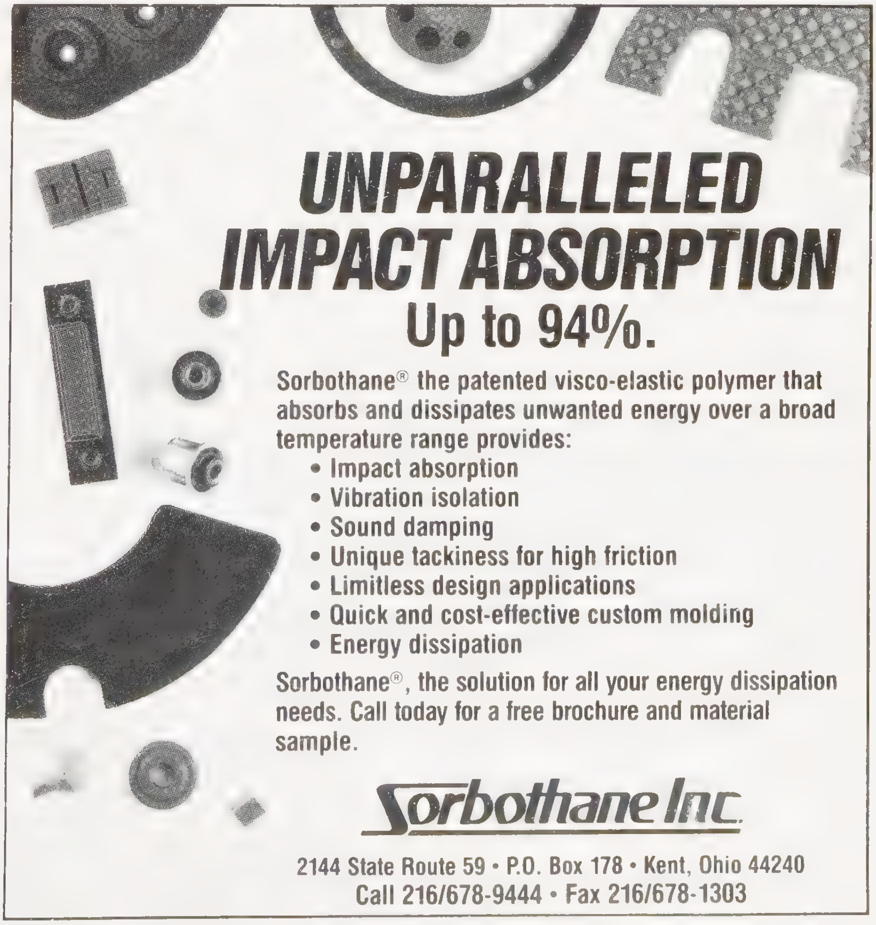
Company ______________________

Address (not P.O. Box) ______________________

City ______________ State ______________ Zip ______________

Signature ______________________

Penton Education Division • 1100 Superior Avenue • Cleveland, Ohio 44114



UNPARALLELED IMPACT ABSORPTION

Up to 94%.

Sorbothane® the patented visco-elastic polymer that absorbs and dissipates unwanted energy over a broad temperature range provides:

- Impact absorption
- Vibration isolation
- Sound damping
- Unique tackiness for high friction
- Limitless design applications
- Quick and cost-effective custom molding
- Energy dissipation

Sorbothane®, the solution for all your energy dissipation needs. Call today for a free brochure and material sample.

Sorbothane Inc.

2144 State Route 59 • P.O. Box 178 • Kent, Ohio 44240
Call 216/678-9444 • Fax 216/678-1303

Circle 623

als are generally vinyls which have platelet-type fillers in them. As the material to which they are applied vibrates, the platelets slide against one another, and this friction between platelets converts the vibration energy into heat.

Free-layer damping material, made from stable vinyl and other polymers, work over an extremely wide frequency (50 to 5,000 Hz) and are very stable over a long period of time (10 to 20 years or more).

The other type of damping is constrained layer. Here, the viscoelastic polymer is homogeneous (not filled) and is sandwiched between two plates. These are bonded together, usually with a structural epoxy adhesive. The ratio of the base thickness to the constraining plate thickness is between 1:1 and 4:1. Better damping is achieved at the 1:1 ratio.

Refractory hard metals

	Wear/impact grades		Corrosion/ wear grade	Gall-resistant grade
	WC+ 7.8%Co	WC+ 12.2%Co	TaC-WC+ Cr-Co	WC+WTiC$_2$+ Co
Tensile strength (10^3 psi)	160	215	50-140	125
Compressive strength (10^3 psi)	670	560	680	610
Hardness, Rockwell A				
At 70°F	89.5	88.0	92.0	91.7
At 1,400°F	75.1	70.8	86.7	77.5
Modulus of elasticity, tension (10^6 psi)	87.9	82.2	77.3	70.1
Coefficient of thermal expansion				
At 70-1,200°F (10^{-6} in./in.-°F)	3.2	3.4	3.6	3.9
Thermal conductivity, 70°F (Btu-ft/h-ft^2-°F)	54.5	56.6	31.2	16.4
Density (lb/in.^{3})	0.53	0.51	0.51	0.40
Electrical resistivity (microhm-cm)				
At 70°F	17.6	19.1	35.9	82.1

There are more than 30 specific RHM structural grades. These data are representative of the range of properties available.

Polymer thickness is determined by the frequencies to be attenuated. Generally, the thicker the polymer, the lower the frequency and conversely the thinner the polymer, the higher the frequency.

Polymer selection is a function of the operating temperature of the material to which it will be applied. Again, each formulation has a finite temperature range over which it will be effective. This temperature range is somewhere in the neighborhood of 80°F, for any given polymer, so that one that works are −20 to 60°F will not be suitable for the 80 to 160°F range. All manufacturers of damping materials give the specific temperature range, frequency, and thickness of the constraining layer.

Damping treatment can achieve considerable noise reduction. As much as 14 dB have been achieved by this method alone, but it must be properly designed.

Gasketing: Although this is a subject which generally receives little attention, it is essential to achieving the full potential of a cabinet enclosure. Gasketing materials are generally soft, pliable foamed vinyls, urethanes, or neoprenes, although other materials are used.

The most important characteristic they exhibit for noise control is sealability or conformability to the irregular surfaces between which they are placed. Closed-cell materials make better gaskets than open cell, but their design is more complicated because they are harder to compress due to the entrapped gas in each cell. This is overcome by extruding them with cross sections having profiles such as "H, X, and Z." Costs for gaskets are minimal compared to the noise reduction they can achieve. A good gasket material properly designed for the application will easily reduce noise by 6 dB or more, and cost about $0.25/linear ft.

Refractory hard metals

Refractory hard metals (RHMs) are a ceramiclike class of materials made from metal-carbide particles bonded together by a metal matrix. Often classified as ceramics and sometimes called cemented or sintered carbides, these metals were developed for extreme hardness and wear resistance.

The RHMs are more ductile and have better thermal shock resistance and impact resistance than ceramics, but they have lower compressive strength at high temperatures and lower operating temperatures than most ceramics. Generally, properties of RHMs are between those of conventional metals and ceramics. Parts are made by conventional powder-metallurgy compacting and sintering methods.

Many metal carbides such as SiC and BC are not RHMs but are true ceramics. The fine distinction is in particle bonding: RHMs are always bonded together by a metal matrix, whereas ceramic particles are self-bonded. Some ceramics have a second metal phase, but the metal is not used primarily for bonding.

Four RHM systems are used for structural applications and, in most cases, several grades are available within each system.

Tungsten carbide with a 3 to 20% matrix of cobalt is the most common structural RHM. The low-cobalt grades are used for applications requiring wear resistance; the high-cobalt grades serve where impact resistance is required.

Tantalum carbide and tungsten carbide combined in a matrix of nickel, cobalt, and/or chromium provide an RHM formulation especially suited for a combination of corrosion and wear resistance. Some grades are almost as corrosion resistant as platinum. Nozzles, orifice plates, and valve components are typical uses.

Titanium carbide in a molybdenum and nickel matrix is formulated for high-temperature service. Tensile and compressive strengths, hardness, and oxidation resistance are high at 2,000°F. Critical parts for welding and thermal metalworking tools, valves, seals, and high-temperature gaging equipment are made from grades of this RHM.

Tungsten-titanium carbide (WTiC$_2$) in cobalt is used primarily for metal-forming applications such as draw dies, tube-sizing mandrels, burnishing rolls, and flaring tools. The WTiC$_2$ is a gall-resistant phase in the RHM containing WC as well as Co. ■

Technical assistance for the section on **Additional engineering materials** was provided by: **Carborundum Co.,** Niagara Falls, NY, Ceramics; **Corning Glass Works,** Corning, NY, Ceramics, Glass; **EAR Specialty Composites,** Indianapolis, IN, Noise-control materials; **Kennametal, Inc.,** Latrobe, PA, Refractory hard metals; **Mykroy/Mycalex, Spaulding Fibre Co. Inc.,** Clifton, NJ, Ceramics; **Norton Co., Industrial Ceramics Div.,** Worcester, MA, Ceramics; **Pure Industries Inc.,** St. Marys, PA, Carbon; **Stackpole Corp.,** St. Marys, PA, Carbon; **Soundcoat Co.,** Deer Park, NY, Noise-control materials; **Tecsyn PMP,** Scottsboro, AL, Engineering ceramics.

A practical handbook to help you design today's sophisticated machines—

STANDARD HANDBOOK OF MACHINE DESIGN
By Joseph E. Shigley and Charles R. Mischke
1,632 pages, 929 illustrations, **$124.50**

The entire subject of machine design is presented with emphasis on solving problems that arise daily in engineering design. The wide range of new materials, new components, new processes, and new analytical tools that have brought great changes in the way machines are designed have been covered to permit the design of machines in the future to meet more rigorous standards of reliability, safety, lighter weight, greater speed, and compactness. Use of computer-aided design methods as well as other machine-computation facilities are integrated throughout the handbook and presented in such a manner that future developments in computer hardware and software will not render the contents of the handbook obsolete.

47 GIANT SECTIONS fully cover every aspect of machine design.

To order your copy, complete the coupon below and mail to: Penton Education Division, 1100 Superior Avenue, Cleveland, Ohio 44114 or, for faster service, call 800-321-7003 (In Ohio, call 216-696-7000).

ORDER FORM

Please send me ____ copy(s) of STANDARD HANDBOOK OF MACHINE DESIGN. I understand that I can review it for 15 days and, if not satisfied, return it for full refund or credit.

☐ My payment is enclosed for postage-free shipment in the U.S. and Canada.
☐ Bill my company and include shipping and handling charges. Company purchase order required.
☐ Charge my: ☐ MasterCard
☐ Visa ☐ American Express Card

Account No. ________________
Exp. Date ________________
Name ________________
____
Company ________________
Address ________________ (No P.O. Box)
City ________________
State ________ Zip ________
Signature ________________

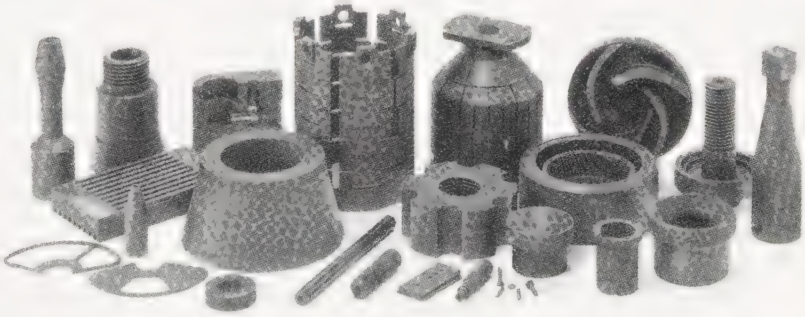
Penton Education Division • 1100 Superior Avenue • Cleveland, Ohio 44114

IF YOU'RE THINKING

TEMPERATURE OR STRENGTH OR MACHINABILITY OR INERTNESS OR COST EFFECTIVENESS

THEN YOU'RE THINKING GRAPHITE

And we think we can help you. UCAR Carbon's engineers will work with you to select the right graphite properties for your application. Our 106 years of experience in solving application problems with graphite is yours to draw on. A world-class team of professionals, supported by the most complete R&D facilities, is ready to answer your most complex graphite questions.
Call us today. 1-800-342-3698. In Ohio, (216) 676-2131.



UCAR CARBON COMPANY INC.
P.O. Box 94617, Cleveland, OH 44101

THINKING IN GRAPHITE.

Circle 624

How To Get Greater Economy and Extended Life From Your Wear Parts

Punishing, high volume production operations need the super-hard, longer-lasting performance of Ferro-TiC® metal matrix composite material to save on costs.

Easily machinable, long-wearing Ferro-TiC naturally withstands heat, cold, corrosion, erosion and stress of high volume operations. Its superior lubricity, hardness, non-abrasive and dampening characteristics offer a smoother, quieter operation with a low coefficient of friction.

With less frequent replacement needed, you save on inventory, labor and production downtime while also improving on production quality and part uniformity.

Stock items available in 72 hours.

Send today for a free Ferro-TiC cost comparison chart.

Alloy Technology
INTERNATIONAL, INC
169 Western Highway
West Nyack, NY 10994

(914) 358-5900

(800) 431-1854

Circle 625

THIS COULD BE YOUR MOST USEFUL MANAGEMENT TOOL.

Fundamentals of PERT — Program Evaluation and Review Technique is an extremely useful technique for managing discrete projects. This course covers: (1) the basic methodology of PERT, (2) advantages and limitations of PERT, (3) preparing PERT charts for complex projects, (4) developing time estimates for PERT activities, and (5) finding and manipulating the critical path of a project to save time and money. $22.00 Mail to: Penton Education Division • 1100 Superior Avenue • Cleveland, Ohio 44114. Or call toll-free outside Ohio — 1-800-321-7003/Ohio customers call 216-696-7000.

Please send me ______ copy/s of PERT. I understand that I may review it for 15 days and, if not completely satisified, may return it for full credit or refund.

☐ Payment enclosed for postage-free shipment (US or Canada)
☐ Bill my company. P.O. enclosed.
Charge my: ☐ MasterCard ☐ Visa
☐ American Express

Account #

Exp. Date

Name

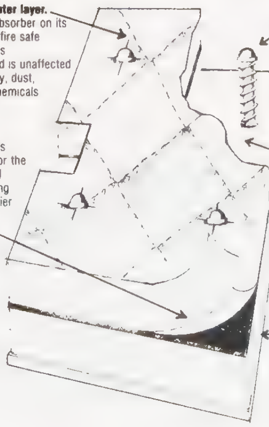
Company

Address (no P. O. Box)

City State Zip

Signature

HOW SOUND SEAL CAN HELP YOU DESIGN FOR EQUIPMENT NOISE CONTROL.



Quilted fiberglass outer layer. An effective sound absorber on its own, this material is fire safe (Class I rating), meets ASTM E-84 (84a) and is unaffected by moisture, humidity, dust, dirt, oils and most chemicals

Spun bonded nylon. This material provides supportive backing for the quilted fiberglass and is an excellent bonding surface with the barrier septum

Total acoustical performance. The composite has an STC up to 33

Installation is simple. Threaded studs are welded to body metal Pre-cut slits in the Sound Seal barrier are positioned over studs which are then capped Adhesives lose effectiveness in an equipment compartment environment

Equipment compartment, transmission housing or body metal. No matter how big, small or odd the size, we can make a barrier to fit With in-house die cutting capabilities we ll meet your specs

Mass loaded vinyl septum. This barrier effectively reflects soundwaves back into the fiberglass absorber

CALL OR WRITE FOR FREE TECHNICAL LITERATURE.

SOUND SEAL

UNITED PROCESS, INC.
P.O Box 545, 279 Silver Street
Agawam, MA 01001
Phone (413) 789-1770
FAX (413) 789-2248

Circle 69 for literature only
Circle 70 to have a salesman call

Managerial Accounting for Non-Financial Managers —

You'll work as a company controller in this programmed learning course. You'll learn to properly record all the company's business transactions and how to prepare financial statements. When the company's fiscal year ends, you'll prepare the annual report, balance sheet, income statement, and the statement of source and application of funds. When you've finished the course, you'll understand better the role of accounting and how to use the information accounting gives you to be a more effective manager. Two volumes . . $32.50 Mail to: Penton Education Division • 1100 Superior Avenue • Cleveland, Ohio 44114. Toll-free outside Ohio, 800-321-7003. Ohio customers call 216/696-7000.

Please send me______copy/s of Managerial Accounting for Non-Financial Managers. I understand that I may review it for 15 days and, if not completely satisfied, I may return it for full credit or refund.

☐ Payment enclosed for postage-free shipment (US & Canada)
☐ Bill my company. P.O. enclosed.
Charge my: ☐ MasterCard ☐ Visa ☐ American Express

Account #

Exp. Date

Name

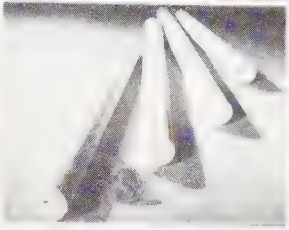
Company

Address (no P. O. Box)

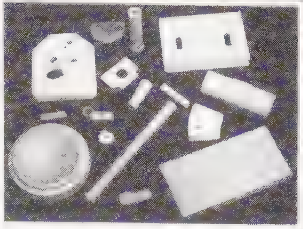
City State Zip

Signature

machinable ceramics?



RAW MATERIALS



FABRICATIONS

Aremcolox™ machinable ceramics are offered both as raw materials and finished parts, with temperature resistance to 3000°F.

Six basic machinable ceramics are available as raw materials in rods and plates, and are easily fabricated by the user using conventional machine shop equipment.

Aremcolox™ machinable ceramics are also offered as fabricated parts, made to your print by Aremco.

Send prints for quotation, or ask for data and pricing on standard shapes.

AREMCO PRODUCTS, INC.

23 Snowden Ave., Box 429
Ossining, NY 10562
(914) 762-0685
FAX: (914) 762-1663

Circle 626

Machine Design

Let us put them to work for you.

Reprints of your advertisements and "Machine Design" articles can be used as:

- ☞ *Direct mail to customers and prospects.*
- ☞ *Sales aids for your people in the field.*
- ☞ *Tools to inform stockholders and employees.*
- ☞ *Training aids for new employees.*
- ☞ *Handouts at trade shows and company meetings.*
- ☞ *New product announcements.*
- ☞ *Follow-ups to ad inquiries.*

For more information about this cost-effective way to get your message out to your customers and staff or to place an order, call Linda L. Fouts, reprints manager, at (216) 696-7000

MACHINE DESIGN is a publication of:
Penton Publishing
1100 Superior Avenue, Cleveland, Ohio 44114

Circle 627

WE GIVE YOU A CHOICE IN CERAMICS, NO MATTER HOW YOU WEAR 'EM.

Diamonite technical ceramics wear characteristics are unparalleled in the industry, resulting in reduced downtime, lower maintenance costs, and superior properties for your OEM products. Diamonite ceramics also provide excellent thermal insulation, corrosion resistance, and are electrically non-conductive.

Our CAD/CAM design system and production capabilities give us the ability to manufacture precision parts to your exacting tolerances. Diamonite offers a choice of high alumina, zirconia, and zirconia alumina blended ceramics to meet your toughest wear, corrosion, or thermal requirements.

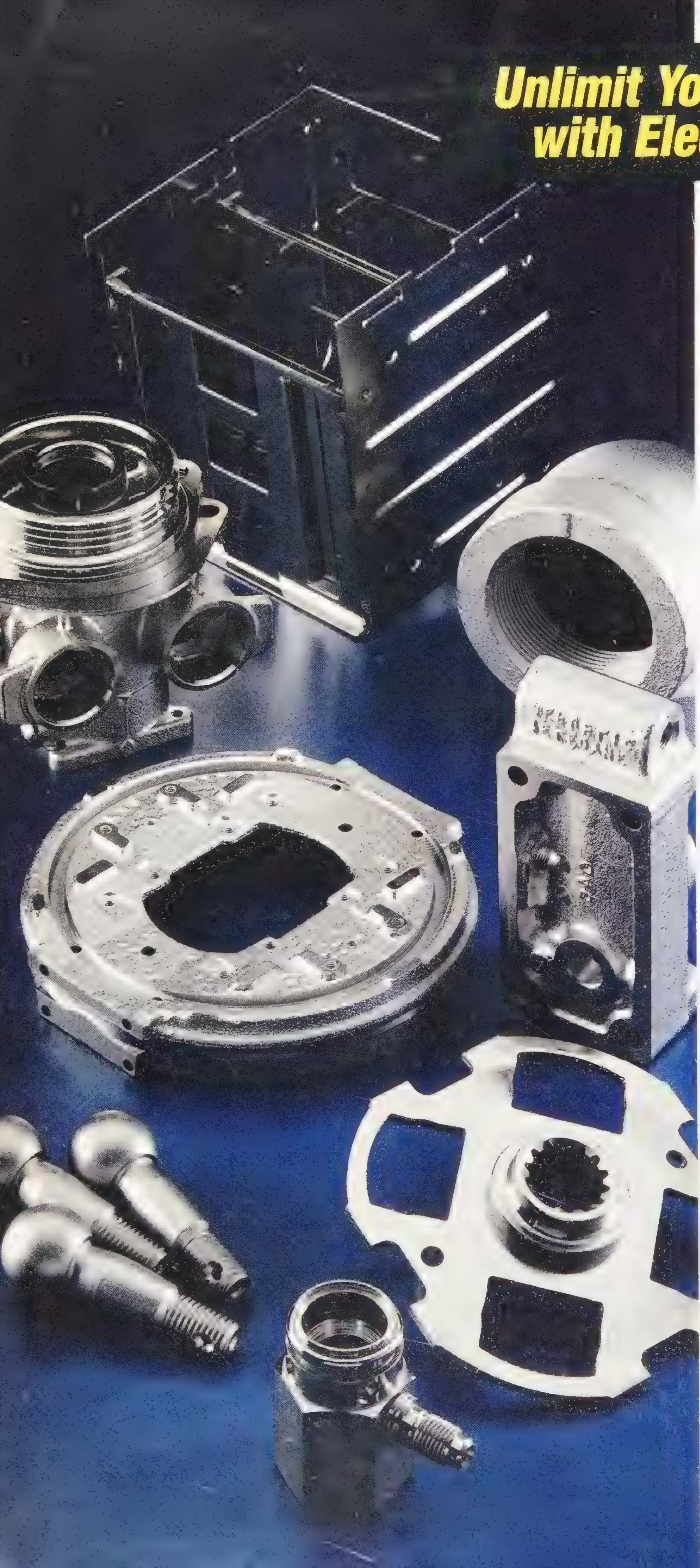
For information on the toughest, most precise ceramics in the industry, call or write: **Diamonite Products**

W. R. Grace & Co. – Conn.
453 W. McConkey Street
Shreve, Ohio 44676
Toll Free 1-800-342-9327
(216) 567-2145
Fax (216) 567-2260

DIAMONITE®

Diamonite Products

Circle 628



Unlimit Your Imagination with Electroless Nickel

Enplate® Electroless Nickel Coatings: A New Level Of Versatility.

Your engineering designs and specifications require increased performance and longer service life; Enplate electroless nickel coatings provide:

- Coating uniformity even on complex parts. Easily specified within 0.00005 inch for greater design flexibility.
- Specific combinations of performance features: corrosion protection, high hardness, wear resistance, abrasion/erosion protection and increased lubricity with a composite nickel-Teflon process.
- Cost effective alternatives to stainless steel, nickel alloys and hard chrome plating. Functional properties coupled with coating smoothness and close tolerances can extend component life and reduce manufacturing costs.

For years, Enplate electroless nickel coatings have been specified on a variety of applications as alternatives to metal and non-metal coating processes. These include automotive power train and fuel applications, batteries and electronic components, food, textile and chemical processing equipment, gas turbine compressors, computer disk drives and more. Enplate electroless nickels enable design engineers to combine high performance, reliability, precision and cost effectivenes

Find out more about the Enplate electroless nickel process for your application call the Electroless Nickel Marketing Grou at (203) 934-8611; write P.O. Box 1900, Nev Haven, CT 06508; FAX (203) 937-1680.

Typical Deposit Properties

Deposit Type	Low Phosphorus (1-3% P)	Medium Phosphorus (4-8% P)	High Phosphorus (9-12% P)	Teflon Composite (25%v/v PTF
Hardness, VHN$_{100}$				
As-Plated	650-750	500-550	450-500	300-350
Heat Treated	1000-1050	875-925	850-900	350-400
Salt Spray Corrosion Resistance per ASTM B-117 @ 1 mil	192 hr.	240 hr.	1000 hr.	1000 hr.
Taber Abrasion Resistance (Weight Loss per 1000 cycles) (1000 g load CS-10 wheel)				
As-Plated	2-4 mg.	14-18 mg.	19-24 mg.	20 mg.
Heat Treated	1-3 mg.	12-15 mg.	15-17 mg.	. . .

Circle 629

ENTHONE®

Enthone-OMI, Inc.

a subsidiary of ASARCO

Coatings, platings, and finishes

The main job of coatings, whether they are simple paints or sophisticated sputtered films, is to protect substrates from damage in service environments.

Even though appearance is often the predominant reason that comes to mind for specifying a coating, it is not the most important. Coatings keep substrate metals from damage by abrasion, erosion, impact, weather, and corrosive environments. Stopping or retarding corrosion is simple in principle. Surrounding a vulnerable metal part with a relatively inert barrier coating — a metal plating or polymer film, for example — prevents corrosives from coming in contact with the substrate metal.

Almost any coating material, as long as it retains its integrity, offers some degree of protection. If it provides a continuous barrier between the substrate and the environment, even a thin, decorative coating can do the job in a relatively dry and mild environment.

Polymer coatings

Polymeric coatings designed for corrosion protection are usually tougher and are applied in heavier films than are appearance coatings. Requirements of such coatings are much more stringent: They must adhere well to the substrate and must not chip easily or degrade from heat, moisture, salt, or chemicals.

Environmental factors also drive the technology behind polymer coatings replacing chrome and cadmium coatings. This is partly due to increasing concern about heavy metals. Also, automakers must now contend with acid rain in addition to salt spray, and polymers surpass chrome and cadmium in acid rain resistance.

Acrylics and alkyds are widely used for farm equipment and industrial products requiring good corrosion protection at a moderate cost. Alkyd resins, particularly, play a major role in maintenance painting because of their good weathering characteristics and ease of application with low-cost, low-toxicity solvents. Alkyd paints are also relatively high in solids, permitting good buildup of a paint film with a minimum number of coats.

Epoxy finishes have better adhesion to metal substrates than do most other organic materials. Epoxies are attractive economically because they are effective against corrosion in thinner films than are most other finishing materials. They are often used as primers under other materials that have good barrier properties but marginal adhesive characteristics.

Coating thickness can vary from 1 mil for light-duty protection to as much as 20 mil for service involving the handling of corrosive chemicals or abrasive materials. Performance of epoxies is limited in the heavier thicknesses, however, because they are more brittle than other organic materials.

Nylon 11 coatings provide attractive appearance as well as protection from chemicals, abrasion, and impact. Applied by electrostatic spray in thicknesses from 2.5 to 8 mil, nylon coatings are used on office and outdoor furniture, hospital beds, vending-machine parts, and building railings. Heavier coatings — to 50 mil — are applied by the fluidized-bed method and are used to protect dishwasher baskets, food-processing machinery, farm and material-handling equipment, and industrial equipment such as pipe, fittings, and valves.

Fluorocarbons are more nearly inert to chemicals and solvents than all other polymers. The most effective barriers among the fluorocarbons for a variety of corrosive conditions are PFA, PTFE, ECTFE, FEP, and PVDF.

For impact service, PVDF and ECTFE coatings are recommended, in that order. PTFE, FEP, and PFA are also suitable, but they have a greater tendency to creep under load. For abrasive conditions, PVDF is outstanding among the fluorocarbons. Recommended for high service temperatures — drying ovens and steam-handling equipment, for example — are PFA and PVDF. These materials are also used on engine components and welders. PVDF also has the highest compressive strength of the fluorocarbons. PTFE has the highest allowable service temperature (600°F) of the fluorocarbons.

Combination coatings blend the advantages of anodizing or hard-coat platings with the controlled infusion of low-friction polymers and/or dry lubricants. The coatings become an integral part of the top layers of metal substrates, providing increased hardness and other surface properties.

These coatings, typified by a series of proprietary coatings developed by General Magnaplate Corp., are different for each class of metals. For example, the company's Tufram coating for aluminum combines the hardness of aluminum oxide and the protection of a fluorocarbon topcoat to impart increased hardness, wear and corrosion resistance, and permanent lubricity.

Metal coatings

Although there are many new materials being developed and used today, steel remains the principal construction material for automobiles, appliances, and industrial machinery. But because of steel's vulnerability to deterioration from aggressive chemical environments or even from simple atmospheric oxidation, coatings are necessary to provide various degrees of protection. The coatings range from hot-dipped and electroplated metals to tough polymers and flame-sprayed ceramics.

In general, corrosive environments contain more than one active material, and the coating must resist penetration by a combination of oxidizers, solvents, or both. Thus, the best barrier is one that resists "broadband" corrosion.

Physical integrity of the coating is as important as its chemical barrier properties in many applications. For instance, coatings on impellers that mix abrasive slurries can be abraded quickly; coatings on pipe joints will cold-flow away from a loaded area if the creep rate is not low; and coatings on flanges and support brackets can be chipped or penetrated during assembly if impact strength is inadequate. Selecting the best coating for an application requires evaluating all effects of the specific environment, including thermal and mechanical conditions.

Zinc: One of the most common and inexpensive protection methods for steel is provided by zinc. Zinc-coated, or galvanized, steel is produced by various hot-dipping techniques, but more steel companies today are moving into electrogalvanizing so they can provide both.

Oxidation protection of steel by zinc operates in two ways — first as a barrier coating, then as a sacrificial coating. If the zinc coating is scratched or penetrated, it continues to provide protection by galvanic action until the zinc layer is depleted. This sacrificial action also prevents corrosion around punched holes and at cut edges.

The grades of zinc-coated steel commercialized in recent years have been designed to overcome the drawbacks of traditional galvanized steel, which has been difficult to weld and to paint to a smooth finish. The newer materials are intended specifically for stamped automotive components, which are usually joined by spot welding and which require a smooth, Class A painted finish.

Among today's improved galvanized steels is Inland Steel's Paint-Tite B family of three products. These galvannealed (heat-treated) steels have a hot-dipped zinc coating on one side and a light, gas-jet-wiped coating on the smooth side. They are thermally treated to provide a uniform, spangle-free, paintable, weldable, zinc-iron alloy coating. Because the zinc-iron crystals on the coated side are very fine, the sheet can be formed or rolled with no "print-through" in the top surface.

Another improved zinc-coated steel is Armco's Ultrasmooth, which has a hot-dipped zinc coating on both sides and surfaces comparable to a Class 1 cold-rolled steel finish. Jets of nitrogen, which surround the steel as it emerges from the molten zinc, control the coating thickness. The resulting surfaces are free from ripples and oxide patterns commonly found on conventional hot-dipped galvanized steels.

Armco's newest zinc-coated product, Electrasmooth, has an electrogalvanized coating on one or both sides. Made by the vertical-cell process, it has a smooth, uniform surface suitable for painted automotive panels, appliance wrappers, and architectural products. Electrasmooth coatings are available on the full range of commercial and drawing-quality grades.

Another new process for zinc coating of steels is Galfan, developed by the International Lead Zinc Research Organization (ILZRO). In addition to zinc, the coating contains mischmetal (a mixture of cerium, lanthium, and other rare-earth metals) and 5% aluminum. Galfan is claimed to provide improved formability and paintability, and to have two to three times the corrosion resistance of conventional, hot-dipped galvanized steel in salt-spray, sulfur-dioxide, and humidity tests.

Aluminum: Two types of aluminum-coated steel are produced, each for a different kind of corrosion protection. Type 1 has a hot-dipped aluminum-silicon coating to provide resistance to both heat and corrosion. Type 2 has a hot-dipped coating of commercially pure aluminum, which provides excellent durability and protection from atmospheric corrosion. Both grades, developed by Armco, the producer of these aluminized steels, are usually used unpainted.

Type 1 aluminum-coated steel resists heat scaling to 1,250°F and has excellent heat reflectivity to 900°F. Nominal aluminum-alloy coating is about 1 mil on each side. The sheet is supplied with a soft, satiny finish. Typical applications include reflectors and housings for industrial heater panels, interior panels and heat exchangers for residential furnaces, microwave ovens, automobile and truck muffler systems, heat shields for catalytic converters, and pollution-control equipment.

Type 2 aluminized steel, with an aluminum coating of about 1.5 mil on each side, resists atmospheric corrosion and is claimed to outlast zinc-coated sheet in industrial environments by as much as five to one. Typical applications are industrial and commercial roofing and siding, drying ovens, silo roofs, and housings for outdoor lighting fixtures and air conditioners.

Electroplating: Use of protective electroplated metals has changed in recent years, mainly because of rulings by the Environmental Protection Agency. Cyanide plating solutions and cadmium and lead-bearing finishes are severely restricted or banned entirely. Chromium and nickel platings are much in use, however, applied both by conventional electroplating techniques and by new, more efficient methods such as Fast Rate Electrodeposition (FRED). This latter method has also been used successfully by Battelle Columbus Labs to deposit stainless steel on ferrous substrates.

Functional chromium, or "hard chrome," plating is used for antigalling and low-friction characteristics as well as for corrosion protection. These platings are usually applied without copper or nickel underplates in thicknesses from about 0.3 to 2 mil. Hard-chrome plating is recommended for use in saline environments to protect ferrous components.

Nickel platings, in thickness from 0.12 to 3 mil, are used in food-handling equipment, on wear surfaces in packaging machinery, and for cladding in

Conversion coatings: Electroless platings are more accurately described as conversion coatings, because they produce a protective layer or film on the metal surface by means of a chemical reaction. Another conversion process, the black oxide finish, has been making progress in applications ranging from fasteners to aerospace. Black oxide is gaining in popularity because it provides corrosion resistance and aesthetic appeal without changing part dimensions.

On a chemical level, black oxiding occurs when the iron within the steel's surface reacts to form magnetite (Fe_3O_4). Processors use inorganic blackening solutions to produce the reaction. Oxidizing salts are first dissolved in water, then boiled and held at 280 to 285°F. The product surface is cleaned in an alkaline soak and then rinsed before immersion in the blackening solution. After a second rinse, the finish is sealed with rust preventatives, which can produce finishes that vary from slightly oily to hard and dry.

Black oxiding produces a microporous surface that readily bonds with a topcoat. For example, a supplemental oil topcoat can be added to boost salt-spray resistance to the same level as that of zinc plate with a clear chrome coating (100 to 200 h).

Black oxide can be used with mild steel, stainless steel, brass, bronze, and copper. As long as parts are scale free and do not require pickling, the finish will not produce hydrogen embrittlement or change part dimensions. Operating temperatures range from cryogenic to 1,000°F.

Sputtering: Formerly used primarily to produce integrated-circuit components, sputtering has moved on to large, production-line jobs such as "plating" of automotive trim parts. The process deposits thin, adherent films, usually of metal, in a plasma environment on virtually any substrate.

Sputtering offers several advantages to automotive manufacturers for an economical replacement for conventional chrome plating. Sputtering lines are less expensive to set up and operate than plating systems. And because sputtered coatings are uniform as well as thin, less coating material is required to produce an acceptable finish. Also, pollution controls are unnecessary because the process does not produce any effluents. Finally, sputtering requires less energy than conventional plating systems.

Chrome coating of plastics and metals is only one application for sputtering. The technique is not limited to depositing metal films. NASA's Lewis

Research Center has successfully sputtered PTFE on metal, glass, paper, and wood surfaces. In another application, cattle bone was sputtered on metallic prosthetic devices for use as hipbone replacements. The sputtered bone film promotes bone growth and attachment to living bone.

Sputtering is the only deposition method that does not depend on melting points and vapor pressures of refractory compounds such as carbides, nitrides, silicides, and borides. As a result, films of these materials can be sputtered directly onto surfaces without altering substrate properties.

Ion plating: The basic difference between sputtering and ion plating is that sputtered material is generated by impact evaporation and transferred by a momentum transfer process. In ion plating, the evaporant is generated by thermal evaporation. Ion plating combines the high throwing power of electroplating, the high deposition rates of thermal evaporation, and the high energy impingement of ions and energetic atoms of sputtering and ion-implantation processes.

The excellent film adherence of ion-plated films is attributed to the formation of a graded interface between the film and substrate, even where the two materials are incompatible. The graded interface also strengthens the surface and subsurface zones and increases fatigue life.

The high throwing power and excellent adherence makes possible the plating of complex three-dimensional configurations such as internal and external tubing, gear teeth, ball bearings, and fasteners. Gears for space applications, for example, have been ion plated with 0.12 to 0.2 μm of gold for lubrication and to prevent cold welding of the gear pitch line. Ion plating has also been used, on a production basis, to plate aluminum on aircraft landing-gear components for corrosion protection.

Ion plating is also one of the two methods used to deposit diamondlike coatings (DLCs). A relative newcomer to the coatings field, DLCs are commonly made from hydrocarbon (often methane) and hydrogen gases heated to 2,000°C. The carbon coatings are prized for their wear resistance, as well as electrical and optical properties. Although they represent a huge potential, present DLCs are at the earliest stages of commercialization. However, their wide range of properties, along with their relatively low cost, leads many to predict huge growth in DLCs.

At Battelle Laboratories in Columbus, Ohio; Geneva, Switzerland; and Frankfurt, W. Germany, development work is continuing on DLCs. Battelle researchers propose the coatings be used to improve wear resistance in tool bits, as electronic heat sinks, and to boost wear and corrosion resistance in optical materials.

Thermal spraying: Arc spraying, a form of thermal spraying of metals, is done on a prepared (usually grit-blasted) metal surface, using a wire-arc gun. The coating metal is in the form of two wires that are fed at rates that maintain a constant distance between their tips. An electric arc liquefies the metal, and an air spray propels it onto the substrate. Because particle velocity can be varied considerably, the process can produce a range of coating finishes from a fine to a coarse texture.

Arc-sprayed coatings are somewhat porous, being composed of many overlapping platelets. Used in applications where appearance is important, thermally sprayed coatings can be sealed with pigmented vinyl copolymers or paints, which usually increase the life of the metal coating. Arc-sprayed coatings are thicker than those applied by hot dipping, ranging from 3 to 5 mil for light-duty, low-temperature applications to 7 to 12 mil for severe service.

Because zinc and aluminum are, under most conditions, more corrosion resistant than steel, they are the most widely used spray-coating metals. In addition, since both metals are anodic to steel, they act galvanically to protect ferrous substrates.

In general, aluminum is more durable in acidic environments, and zinc performs better in alkaline conditions. For protecting steel in gas or chemical plants, where temperatures might reach 400°F, aluminum is recommended. Zinc is preferred for protecting steel in fresh, cold waters; in aqueous solutions above 150°F, aluminum is the usual choice.

For service to 1,000°F, a thermally sprayed aluminum coating should be sealed with a silicone-aluminum paint. Between 1,000 and 1,650°F, the aluminum coating fuses and reacts with the steel base metal, forming a coating that, without being sealed, protects the structure from an oxidizing environment. And, for continuous service to 1,800°F, a nickel-chrome alloy is used, sometimes followed by aluminum.

In Europe, where thermally sprayed metal coatings for corrosion protection have been far more widely used than in the U.S., many structures such as bridges are still in good condition after as long as 40 years, with minimum maintenance. Other applications include exhaust-gas stacks, boat hulls, masts, and many outdoor structures.

Plasma spraying: Plasma-spray coating relies on a hot, high-speed plasma flame (nitrogen, hydrogen, or argon) to melt a powdered material and spray it onto the substrate. A direct-current arc is maintained to excite gases into the plasma state.

The high-heat plasma (in excess of 15,000°F) enables this process to handle a variety of coating materials — most metals, ceramics, carbides, and plastics. Although most coating materials are heated to well beyond their melting points, substrate temperatures commonly remain below 250°F.

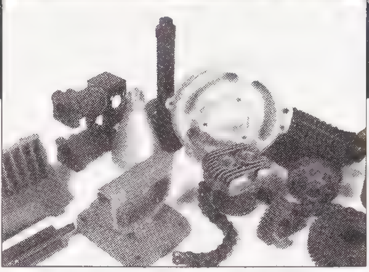
This process has found wide acceptance in the aircraft industry. Plasma-sprayed metallic coatings protect turbine blades from corrosion, and sprayed ceramics provide thermal-barrier protection for other engine parts.

Detonation gun coatings, developed by Union Carbide and considered by many to be an industry standard, use a detonation wave to heat and accelerate powdered material to 2,400 fps. In the line-of-sight process, each individual detonation deposits a circle of coating with a 1 in. diameter and 2 μm thickness. Coatings, thus, consist of multiple layers of densely packed lenticular particles tightly bonded to the surface.

The Super D-Gun, Union Carbide's next generation, has been developed to increase particle velocities. New coatings (the UCAR 2000 Series) applied with the gun offer improved wear resistance without affecting fatigue performance. The system has been targeted for fatigue-sensitive aircraft components. ■

Technical assistance for the **Coatings, platings, and finishes** section was provided by **Aluminum Co. of America,** Pittsburgh, PA, Metal coatings; **APS Materials Inc.,** Dayton, OH, Thermal-barrier coatings; **Armco Inc.,** Middletown, OH, Metal coatings; **Battelle Laboratories,** Columbus, OH, Metal coatings; **Beam-Alloy Corp.,** Dublin, OH, Metal coatings; **Brunswick Technetics,** Deland, FL, Metal coatings; **Cleveland Black Oxide,** Cleveland, OH, Metal coatings; **The Du Pont Co., Fabricated Product Dept., Teflon Finishes,** Wilmington, DE, Polymer coatings; **General Magnaplate Corp.,** Linden, NJ, Polymer coatings; **The Glidden Co.,** Cleveland, OH, Polymer coatings; **International Lead Zinc Research Organization Inc.,** Research Triangle Park, NC, Metal coatings; **Lewis Research Center, NASA,** Cleveland, OH, Metal coatings; **Lord Corp., Industrial Coatings Div.,** Erie, PA, Polymer coatings; **Metallic Bonds Ltd.,** Beloit, WI, Metal coatings; **Nimet Industries,** South Bend, IN, Metal coatings; **Pure Industries Inc.,** St. Marys, PA, Metal coatings; **Union Carbide Corp., Coatings Service,** Indianapolis, IN, Metal coatings; **Weirton Steel Corp.,** Weirton, WV, Metal coatings; **Whitford Corp.,** Frazer, PA, Polymer coatings; **Zinc Institute,** New York, NY, Metal coatings.

Protect metal parts against corrosion, wear, abrasion and sticking.



Magnaplate "synergistic" coatings create a harder-than-steel, non-stick surface that improves wear and performance

Magnaplate-applied surface enhancement coatings dramatically improve wear and performance by creating a super-hard, non-stick, dry-lubricated surface that won't chip, peel or rub off. They become an integral part of the metal substrate. Coated parts exhibit even better abrasion and corrosion resistance than stainless steel. Non-stick, low-COF properties permit superior mold release, improve material flow, and solve sanitation clean-up problems without the use of environmentally-unsafe chemicals. Many meet USDA/FDA codes. Call for ENGINEERING DATA GUIDE.

General Magnaplate

1331 Rt.1, Linden, NJ 07036 • (908) 862-6200 • FAX (908) 862-6110
Arlington TX (817) 649-8989 • Ventura CA (805) 642-6262
Racine WI (414) 637-5673 • Ajax, Ont., Canada (416) 686-2277

Circle 630

Managerial Accounting for Non-Financial Managers

You'll work as a company controller in this programmed learning course. You'll learn to properly record all the company's business transactions and how to prepare financial statements. When the company's fiscal year ends, you'll prepare the annual report, balance sheet, income statement, and the statement of source and application of funds. When you've finished the course, you'll understand better the role of accounting and how to use the information accounting gives you to be a more effective manager. Two volumes . . . $32.50 Mail to: Penton Education Division • 1100 Superior Avenue • Cleveland, Ohio 44114. Toll-free outside Ohio, 800-321-7003. Ohio customers call 216/696-7000.

Please send me______copy/s of Managerial Accounting for Non-Financial Managers. I understand that I may review it for 15 days, and, if not completely satisfied, I may return it for full credit or refund.

☐ Payment enclosed for postage-free shipment (US & Canada)
☐ Bill my company. P.O. enclosed.
Charge my: ☐ MasterCard ☐ Visa
☐ American Express

Account #
Exp.Date
Name
Company
Address (no P. O. Box)
City State Zip
Signature

Two High Lubricity Coatings

A WORLD OF APPLICATIONS

Specify **Nituff**® and **NiCoTef**® for low friction and high resistance to corrosion, abrasion and galling.

Nituff Teflon* penetrated aluminum hardcoat anodizing permits lightweight design applications with file-hard, self-lubricating surface finishes.

NiCoTef advanced composite coating autocatalytically codeposits Teflon throughout a nickel/phosphorus matrix - enhances most metal substrates, provides dry lubrication and yields uniform coating thickness for close design tolerances.

Nituff and **NiCoTef**...available only from Nimet Industries. Call or write for technical information.

*Teflon is a Du Pont registered trademark

NIMET INDUSTRIES, INC.

2424 N. Foundation Drive
P O. Box 3628, South Bend, IN 46619
Telephone: 219-287-7239 • Telefax: 219-287-0777

Machine Design

Let us put them to work for you.

Reprints of your advertisements and "Machine Design" articles can be used as:

- ☞ *Direct mail to customers and prospects.*
- ☞ *Sales aids for your people in the field.*
- ☞ *Tools to inform stockholders and employees.*
- ☞ *Training aids for new employees.*
- ☞ *Handouts at trade shows and company meetings.*
- ☞ *New product announcements.*
- ☞ *Follow-ups to ad inquiries.*

For more information about this cost-effective way to get your message out to your customers and staff or to place an order, call Linda L. Fouts, reprints manager, at (216) 696-7000

MACHINE DESIGN is a publication of:
Penton Publishing
1100 Superior Avenue, Cleveland, Ohio 44114

MATERIALS

Write this number on the Reader Service Card to receive information from all advertisers making the listed products.

FERROUS METALS

1427	Electrical alloys
1428	High alloys
1429	High-strength, low alloys
1430	High-temperature steels
1431	Magnetic alloys
1432	Refractory
1433	Specialty steels
1434	Stainless steel

NONFERROUS METALS

1435	Aluminum
1436	Beryllium
1437	Brass
1438	Bronze
1439	Copper
1440	Nickel
1441	Refractory
1442	Other

PLASTICS

1443	Additives
1444	Epoxy
1445	Filled
1446	Nylon
1447	Other plastics
1448	Phenolic-filled
1449	PTFE
1450	Reinforced
1451	Rigid urethane
1452	Urethane

RUBBER, ELASTOMER

1453	Elastomeric plastics
1454	Flexible silicone
1455	Rubber, hard
1456	Rubber, natural
1457	Rubber, synthetic
1458	Rubber, other
1459	Sealants

OTHER NONMETALS

1460	Carbon
1461	Carbon, cast
1462	Ceramics
1463	Glass
1464	Graphite
1465	Quartz

COATINGS

1466	Ceramic coatings
1467	Chemical coatings
1468	Conversion coatings
1469	Electrochemical coatings
1470	Impregnation
1471	Metallic coatings
1472	Plastic coatings
1473	Other coatings
1474	Electroplating
1475	Mechanical surface finishes
1476	Organic finishes
1477	Painting
1478	Rust solvents
1479	Solvents

PREFABRICATED FORMS

1480	Conductive materials
1481	Friction materials
1482	Graphite
1483	High-modulus composites
1484	Insulating materials
1485	Plastic trim
1486	Sheet
1487	Shielding
1488	Sponge rubber
1489	Stock metal
1490	Structural plastic
1491	Structural rubber
1492	Tubing channels
1493	Wire cloth

MANUFACTURING PROCESSES

1494	Casting, centrifugal
1495	Casting, continuous
1496	Casting, die
1497	Casting, metal
1498	Casting, plaster mold
1499	Casting, sand
1500	Casting, other
1501	Forgings

METAL FORMING, SHAPING

1502	Blanking
1503	Compression forming
1504	Extrusions, impact
1505	Gear shaping
1506	Hot isostatic pressing
1507	Roll forming
1508	Spinning
1509	Stamping
1510	Stretch forming
1511	Tube forming
1512	Water jet cutting

METAL JOINING

1513	Joining

METAL REMOVAL

1514	Abrasives
1515	Grinding

METAL TREATING

1516	Shot peening
1517	Other

FINISHING

1518	Chemical, solvent cleaning
1519	Hard facing
1520	Flame spraying
1521	Metal spraying
1522	Mechanical
1523	Plasma arc
1524	Plasma spray
1525	Vacuum metallizing

PLASTICS, RUBBER PROCESSES

1526	Casting, plastic
1527	Extrusions, plastic
1528	Extrusions, rubber
1529	Injection molding
1530	Rubber fabricating
1531	Rubber forming
1532	Rubber molding
1533	Rubber plating
1534	Rubber, plastic stamping
1535	Other rubber processes

PLANT EQUIPMENT

1537	Hand tools
1538	Machine tools

ADVERTISING INDEX

A&A Manufacturing Co., Inc. .215
AMP, Incorporated.........581-590
ARO Corporation 641
AVM, Incorporated, An Arvin Co. 163
ACE Controls, Inc. 744-745
Ace Controls, Inc./Flairline ...725
Air-Mite Devices, Incorporated 705
Alfco 913
Algor, Inc.............................IBC
Alloy Technology International, Inc. 953,974
American Centrifugal, A Div. of American Cast Iron Pipe Co. 657
American Precision Industries, Inc.Deltran Div. 131
American Small Business Computers, Inc. 783,787,797,805
American Variseal, A Div. of W.S. Shamban & Co. 221
Ames Rubber Corporation ...906
Ametek, Incorporated ...469,605
Anaheim Automation 48
Anchor Bolt & Screw Co. 361
Anorad Corporation 442
Apple Rubber Products, Inc. 209-212
Aremco Products, Incorporated 327,975
Aries Technology, Inc. 789
Arlon 953
Associated Spring, Barnes Group Inc. 377
Autodesk, Inc. 72-73
Automatic Switch Company 697-700

BASF Corporation 849,861
BEI Motion Systems Company 535
Baldor ....BC
Bal Seal Engineering Company, Incorporated ...215
Barden Corporation, The 285
Barksdale Controls Division, IMO Industries Inc.............703
Bayside Controls, Inc.......17,172 173,451
Bearings Incorporated ...257-264
Berg, Winfred M., Inc. ...4-5,76-77 268-269
Bimba Manufacturing Company 753-756
Bison Gear & Engineering Corporation 435,461-465
Browning Mfg.-Emerson Power Transmission Corp. 197
Burgess SAIA, Inc...............528
Busch, Inc. 686

Cadkey, Incorporated......791-794
Calcomp, A Lockheed Company 808
Camcar Division of Textron, Inc...............363-366
Camloc Products/Fairchild Fastener Group ...343-346,351-354
Carlon 599-602
Carlyle Johnson Machine Co., The..........................165
Carpenter Technology, Carpenter Steel Div. ...937-940
Carr Lane Mfg. Co. 321-322
Circle Seal Controls 705
Clippard Instrument Laboratory, Inc. 691-694
Colder Products Company ...646
Commercial Intertech Corporation 760-762
Computervision 777-780
Crouzet Corporation 527
Courtaulds Performance Films 849
Cunningham Industries, Inc. 207

Da/Pro Rubber, Inc. 907
Deschner Corporation 724
Diamonite 975
Dodge/Reliance Electric ...19-21 94-95,112-114,126-127,176-183 248-253
Dover Instrument Corporation 123
Driv-Lok Incorporated 381
Du Pont, E.I. de Nemours, Inc., Polymers 867,869,871
Duff-Norton 131
Dynacast Incorporated 918
Dynacorp-Emerson Power Transmission Corp. 199
Dynamics Research Corporation 499-502
Dynaroll Corporation 307

E.A.R. Specialty Composites Corporation 965-968
Eagle Electric Mfg. Co., Inc. 535
Eaton Corporation Airflex Division 151-154
Eaton Corporation, Engineered Fasteners Division 349,391
Eberhard Manufacturing 393
Efson, Inc. 131
Electri-Flex Company 650
Elmo Motion Control Inc. 87
Emerson & Cuming, A Grace Company 578
Emerson Power Transmission Corp. ...197-200
Enidine Incorporated ...711-714
Enthone - OMI, Inc. 976
Eriez Magnetics 8
Eskay...............................368
Evolution Computing ...802-803

FAG Bearings Corporation 290
Fairchild Aerospace Fastener Division 340-341
Federal Brass Manufacturing Company, Inc. 653
Festo Corporation 747-750
Firestone Industrial Products Company 721
Fishercast Div. of Fisher Gauge Limited...........925-928
Fishertech, Division of Fisher Gauge Ltd. 311-314
Flojet Corporation 685
Fluid Line Products, Inc. 646
Force Control Industries, Inc. 149
Fuji Electric Corporation of America 612
Furon, Mechanical Seal Division...........................207

GAM Enterprises Inc. 170
GE Plastics 847
Garlock Bearings Incorporated 239-242
General Magnaplate 980
Gesipa Fasteners USA, Inc....386
Gibbs Die Casting Aluminum Corp. 921
Gilian Instrument Corporation 687
Gorman-Rupp Industries 685
Graham-White Manufacturing Co. 685
Graphite Metallizing Corporation 280
Graseby Volkmann 493

Gray & Prior ...165
Groov-Pin, Inc. ...384

Habasit Belting, Inc. ...103-106
Harmonic Drive Technologies ...186-189
Harrington & King Perforating Co., Inc. ...913
Harting Elektronik, Inc. ...611
Helac Corporation ...724
Hi-Lo Manufacturing Company ...147
Hobbs Corporation ...517
Hoechst Celanese Corporation ...852-853
Hoechst Celanese Corp., PBI Performance Parts ...839-842
Houston Instrument ...810-811, 813-821,823
Hurst Manufacturing Div., Emerson Electric Co. ...441
Hynes ...943

IKO International, Inc. ...299
IMO Industries, Inc. ...IFC,1
IMO Industries Inc., Pump Division ...674-675
INA Bearing Company, Inc. ...267
ITW Philadelphia Resins ...861
ITW Spiroid ...195
Industrial Devices ...485-488
Industrial Drives, A Kollmorgen Div. 11-15,445-448
Industrial Indexing Systems, Inc. ...68-69
Industrial Retaining Ring Co. 382
Inertia Dynamics/ Reliance Electric ...166
Inertial Motors Corp. ...441
Inland Motor, Kollmorgen Corp. 407,409,411,413,415,417,419,421
Intech ...215,861
Intergraph ...799
Interroll ...289

Joyce/Dayton Corporation ...166

Kanematsu USA, Inc. ...131,167
Kleerdex Company ...849

Lee Company, The ...705
Legris Incorporated ...649
Lexington Company, The ...355
Linear Industries, LinTech Division ...123
Long Lok Fasteners Corp. ...399

MMFG ...358
Mabuchi Motor America Corp. ...441
Machine Components Corporation ...165,205
Machine Design Research ...887-888
MagneTek, Inc. ...432-433
Mallory Controls ...494
March Mfg. Co. Inc. ...658
Marlboro Manufacturing, Inc. 399
Master Bond Inc. ...327
Matrix Engineering Limited ...167
Mayr Corporation ...129
McGill Mfg.-Emerson Power Transmission Corp. ...200
McLean Engineering ...612
Merkle-Korff Industries ...443
Mico Incorporated ...708
Micro Engineering Solutions 801
Micro Motors, Inc. ...475
Micro Pneumatic Logic, inc. 527
Micro-Precision Operations Inc./Subs. of Textron Inc. ...735
Milwaukee Cylinder ...757
Minor Rubber Company, Inc. 909
Morse Industrial-Emerson Power Transmission Corp. 198
Mosier Industries, Inc. ...737-740

Namco Controls, An Acme-Cleveland Co. ...513
New Hampshire Ball Bearings, Inc. ...245
NewAge Industries ...653
Niagara Gear ...205
Nimet Industries, Inc. ...980
Nook ...157-160
Norgren ...715
Northern Research & Engineering Corporation ...806

Ogura Clutch ...131,167
Ohio Gear, A Division of Regal-Beloit Corporation ...194
Oildyne, A Unit of Commercial Intertech Corporation ...759
Oilgear Company, The ...684
Oil-Rite Corporation ...307
Oriental Motor U.S.A. Corporation ...437-440
Ormec ...79-86
Oven Industries, Inc., Industrial Controls Div. ...536

PIC Design ...122
Pacific Data Products ...827
Panduit Corporation ...389
Paneloc Corporation, The ...403
Parker Hannifin Corp., Compumotor Div. ...33-46
Parker Hannifin Corporation, Cylinder Division ...723
Parker Hannifin Corporation, Daedal Division ...33-46
Parker Hannifin Corp., Fluid Connectors Group ...619-622
Parker Hannifin Corporation, Fluid Power Group ...23-26
Parker Hannifin Corporation, Hose Products Division ...633
Parker Hannifin Corporation, Parflex Division ...639
Parker Hannifin Corporation/ Rotary Actuator Div. ...743
Parker Hannifin, Tube Fittings Division ...643
Parker Schrader Bellows ...6
Parker Seal ...226-229,497
Penn Engineering & Manufacturing Corp. ...607
Pepperl&Fuchs, Inc. ...530
Pittman, A Div. of Penn Engineering & Mfg. Corp. ...453,455
Plan Hold Corporation ...830
Polyspede Electronics Corporation ...491
Porex Technologies, Inc. ...868
Portescap U.S. Inc. ...423-430
Potter & Brumfield Inc. ...505-509
Pow-R-Jac, Division of Limitorque Corporation ...148
Precision MicroControl Corporation ...48
Precision Tube Company, Inc. ...653
Presray Corporation ...222

Renco Encoders, Inc. ...537
Rexroth Corporation, The, Mobile Hydraulics Div. ...709
Rexroth Worldwide Hydraulics ...763
Rittal Corporation ...594-595

MACHINE DESIGN

1100 Superior Ave Cleveland, OH 44114-2543
216/696-7000 TWX: 810/421-8245

BUSINESS STAFF

Joseph M. DiFranco Publisher
JOSEPH A. FRISTIK .... National Sales Mgr
RAYMOND E. HERZOG .... Research Mgr
JANE MALONEY COOPER .... Promotions Mgr
LORI E. CLEMENTE .... Circulation Mgr
ELAINE L. TOMANEK .... Adv. Svc. & Production Mgr
LAUREL L. HIRKALA .... Card Pack/Special Svc. Mgr
LOIS WALSH .... Recruitment Advertising
NEW JERSEY 07604: BILL BAUMANN
611 Route 46 West
Hasbrouck Heights, NJ 07604 .... 201/393-6060
HARTFORD, CONN: ALAN C. BUGBEE
37 Fox Den Rd.
West Simsbury, CT 06092 .... 203/658-4764
BOSTON: MARK H. SCHELLING
400 5th Avenue
Waltham, MA 02154 .... 617/890-0891
PHILADELPHIA: ROBERT H. OLMSTED, BILL BAUMANN
Gwynedd Plaza, Suite 301
Spring House, PA 19477 .... 215/628-4880
PITTSBURGH 15222: MICKEY AQUILINO
Four Gateway Center, Suite 1510 .... 412/281-8455
CLEVELAND 44114-2543: SCOTT SCHUMACKER, TOM MCINTYRE, MICKEY AQUILINO
1100 Superior Ave. 216/696-7000
CHICAGO: SEYMOUR RECKLES, CHARLES M. ORMISTON, BILL CAMPBELL
Two Illinois Center Bldg., Suite 1300
233 N. Michigan Ave. 312/861-0880
DALLAS 75251: DICK CARPENTER
12201 Merit Drive, Suite 200
Dallas, TX 75251 .... 214/343-1926
LOS ANGELES: LEN PETTEK, DICK CARPENTER
16255 Ventura Blvd., Suite 300
Encino, CA 91436 .... 818/990-9000
SAN FRANCISCO: DAVID W. CHEW
840 Hinckley Rd., Suite 233
Burlingame, CA 94010 .... 415/692-1381
DENVER 80224: ALBERT D. ROSS
3215 South Newport Street 303/753-1901
DETROIT: MICKEY AQUILINO
1100 Superior Ave.
Cleveland, OH 44114-2543 .... 216/696-7000
ATLANTA 30326: DARRYL L. BERMAN
3400 Peachtree Rd., N.E. Suite 811 .... 404/237-5528
WISCONSIN & MINNESOTA: BILL CAMPBELL
Two Illinois Center Bldg., Suite 1300
Chicago, IL 60601 .... 312/861-0880
CANADA: TOM MCINTYRE
1100 Superior Ave.
Cleveland, OH 44114 .... 216/696-7000
TOYKO, JAPAN: AKIYOSHA KOJIMA
Bancho Media Service
Telephone 81-3-3252-2721
Fax: 81-3-3252-2780
UK: JOHN ALLEN, Gen. Mgr. European Operations
Penton Publishing Company
Telephone 0993-778-077
Fax: 44-993-778-246
U.K.: JOHN MAYCOCK
John Maycock Associates
Telephone 0742-759-186
Fax: 0742-781650
ITALY: CESARE CASIRAGHI
Carisaghi cesare sas
Telephone 031-536003
Fax: 031-536007
WEST GERMANY: FREDRICH K ANACKER
Inter Media Partners GMBH
Telephone .... (0202)711091-92
Fax: .... (0202)712431
FRANCE: FABIO LANCELLOTTI
Defense & Communication
Telephone 33-142940244
Fax: 33-143872729
HOLLAND: W.J.M. SANDERS
S.I.P.A.S Oosterpart 6
Telephone 31-2997-1303
Fax: 31-2997-1500
ISRAEL: IGEL ELAN
Elan Marketing Group
Telephone 011-972-3-6952967
Fax: 011-972-3-268020
TAIWAN: CHARLES C.Y. LIU
United Pacific Int'l. Inc.
Telephone 715-0751
Fax: 886-2-716-9493
KOREA: YCUNG SANG JO
Business Communications, Inc.
Telephone 739-7840
Fax: 732-3662
CHINA, HONG KONG: TOM GORMAN
China Consultants Int'l. (HK) Ltd.
Telephone 5 8332181
Fax: 5-8934290
SINGAPORE: OMER SOKER
Media Development Ltd.
Telephone .... 5—8345978
Fax: 5-8939411
CHINA, BEIJING: CANDY WONG
HDM DYR Advtg. Co., Ltd
Telephone 408-1493
Fax: 408-2319
BELGIUM: CHRISTIAN DESMET
Vuurgatstraat 92
3090 Overijse

ABP
Published by
PENTON PUBLISHING
Chairman & CEO, SAL F. MARINO
President & COO, DANIEL J. RAMELLA
President, Design Engineering Group, JAMES W. ZAREMBA
BPA

ADVERTISING INDEX

Robertshaw, Tennessee Division 232-233,304-305
Rogers Corporation 959-963
Rolex Company, National Disc Spring Division 389
Rosemount Inc., Aerospace Division 525
Rotor Clip Company 388

S.C. Hydraulics 687
SEW Eurodrive, Inc. 193
SPS Technologies, Aerospace Products Div. ...359
Sandusky International 2
Seal Master Corp. 217-220
Sepac, Inc. 169
Sheffer Corporation 727-734
Siemens Industrial Automation 29-31
Simmons Fastener Company 398,400,402
Smalley Steel Ring Company 370-373
SoMat Corporation 529
Sorbothane, Inc. 971
Southco, Inc. 396-397
Specken Drumag Company, Inc. 752
Stabilus 389
Stafast Products, Inc. 355
Stahl Specialty Company 922
Star Linear 271-274
Stewart-Warner Hobbs Corporation 517
Stimpson Company, Inc. 375,379,383,387
Stock Drive Products/Sterling Instrument, Div. of DSG ...121
Stocker Hinge Manufacturing Company ...392
Structural Research and Analysis Corporation 785
Sumitomo Machinery Corporation of America ...203
Superior Electric Company, The 70-71,456-457
SUSPA, Inc. 717-720
Swagelok Company 627-630
Swanson Analysis Systems, Inc. 774

THK America, Inc. 283
Tech-Assist Corporation 119
Techno, A DSG Company ...117
Teledyne Gurley 521
Tempil 535
Thomas Industries, Inc. 665-670
Thomson Industries, Inc. 49-53,65
Thomson Industries, Inc., Nyliner Division 279
Thomson Saginaw Ball Screw Company 91
Tol-O-Matic, Inc. 724
Torrington Company, The ...287
Transducer Techniques 536
Tridair Fasteners,Fairchild Fastener Group 340-341
Trim-Lok, Inc. 910
Tuthill Pump Division, Tuthill 661

UCAR Carbon Co., Inc. 973
USA Tolerance Rings 386
Uniform Tubes, Inc. 645
Union Carbide Chemicals & Plastics Specialty Chemical Division 635
United Process, Inc. 974

Vickers, Inc. 688

Warner Electric/Dana Corp. 57-63,66-67,108-110, 134-146,478-480
S.S. White Industrial Products 167
T.B. Wood's Sons Company 97-100

Yardley Products Corporation 357

Zero-Max/Helland Research Engineering 48

Every effort is made to ensure that this index is accurate. However, the publisher cannot be responsible for errors or omissions.

GET A FREE SUBSCRIPTION TO MACHINE DESIGN.
If you do not currently receive **MACHINE DESIGN**
send in the subscription request card.

Reader Service Dept.

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS MAIL PERMIT NO. 25012 CLEVELAND, OH

POSTAGE WILL BE PAID BY ADDRESSEE

MACHINE DESIGN
A Penton Publication
1100 SUPERIOR AVENUE
CLEVELAND OH 44197-8024

GET PRODUCT INFORMATION THE EASY WAY:
• *Send the "bingo" Reader-service card to*
MACHINE DESIGN

Reader Service Dept.

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS MAIL PERMIT NO. 25012 CLEVELAND, OH

POSTAGE WILL BE PAID BY ADDRESSEE

MACHINE DESIGN
A Penton Publication
1100 SUPERIOR AVENUE
CLEVELAND OH 44197-8024

Circulation Dept.

Place
19¢
1st Class
Postage
Here

MACHINE DESIGN
A Penton Publication
P O BOX 985015
CLEVELAND OH 44198-5015

Circulation Dept.

Place
19¢
1st Class
Postage
Here

MACHINE DESIGN
A Penton Publication
P O BOX 985015
CLEVELAND OH 44198-5015

Circulation Dept.

Place
19¢
1st Class
Postage
Here

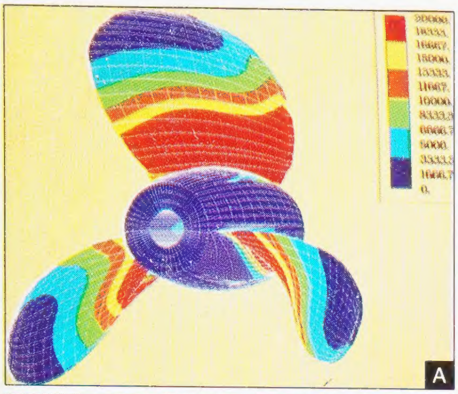
MACHINE DESIGN
A Penton Publication
P O BOX 985015
CLEVELAND OH 44198-5015

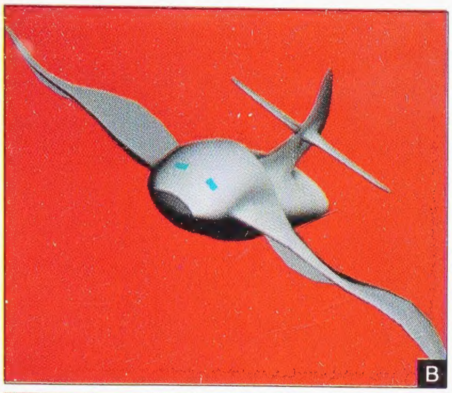
GET A FREE SUBSCRIPTION TO MACHINE DESIGN.

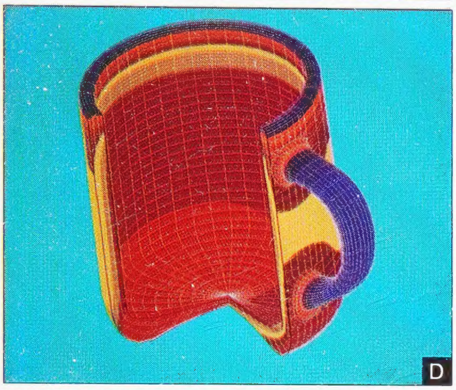
If you do not currently receive **MACHINE DESIGN**, *send in the subscription request card.*

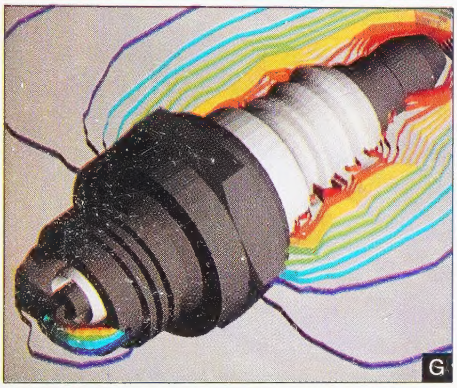
GET PRODUCT INFORMATION THE EASY WAY:

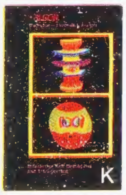
- *Send the "bingo" Reader-service card to* **MACHINE DESIGN**.

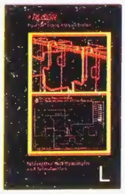












Step Up to Algor

Join more than 6,000 engineers in 50 states and over 60 countries who have stepped up to Algor. Get the most advanced finite element analysis and design software money can buy. All models on this page are FEA models which were designed, analyzed and visualized on a PC with Algor software. The largest contains more than 24,000 nodes and 13,000 elements. Other Algor analysis packages include buckling, nonlinear gap/cable, specialized vibration, composite elements, kinematics/dynamics, piping and many more.

Algor, a PC and You...The Total Design and Engineering Team

Algor is the world's leading design and analysis software for PCs because it is specifically designed to fully exploit their increasing high level of power. Tight bridges to CAD/CAM, desktop publishing and other software create a seamless fit into your environment. Algor design software provides parametric design and results visualization tools (see actual screen photographs on this page) that are worthy of your expertise and creativity. And the engineering is built in.

	Typical Algor Engineering Software Packages	386/486 Price
A	Linear Stress Analysis with ViziCad Plus	$1500
B	Stress, Vibration and Mode Shape Analysis with ViziCad Plus	$2100
C	Fluid Flow Analysis with ViziCad Plus	$1100
D	Heat Transfer Analysis with ViziCad Plus	$1800
E	Accupak—3-D Nonlinear Stress & Vibration (Requires Linear Stress and Vibration)	$2500
F	Iconnex V EAGLE for Concurrent Engineering and Design Optimization	$2300
G	Electrostatic Analysis with ViziCad Plus	$1600

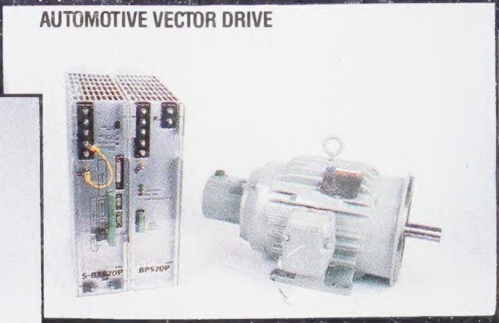
Interactive Demonstration/Tutorials - $19 to $49					
H	Finite Element Analysis	I	Heat Transfer	J	Fluid Flow
K	Electrostatic	L	PipePlus	M	Free 36-Pg Product Guide
N	Your current PC has much more computing power than your last one. Your next PC will have even more. Algor software is constantly updated to take advantage of the full power of the new PCs.				

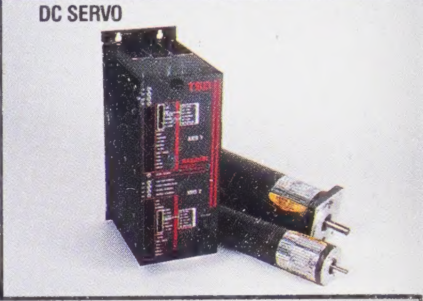
Note: Above prices, shown in U.S. $, may change at any time. **386/486 software** directly uses extended memory. **Weitek** coprocessor and selected Unix workstation versions available. **Algor software is subjected to nuclear power industry Quality Assurance standards.**

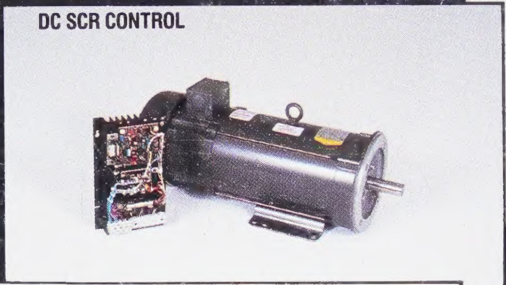
ALGOR®
150 Beta Drive,
Pittsburgh, PA 15238-2932 USA
412-967-2700 • Fax: 412-967-2781
In California: 714-564-2541
Tokyo: 03-3589-6148 • Fax: -6149

Circle 654

BALDOR®
MOTORS AND DRIVES


AUTOMOTIVE VECTOR DRIVE

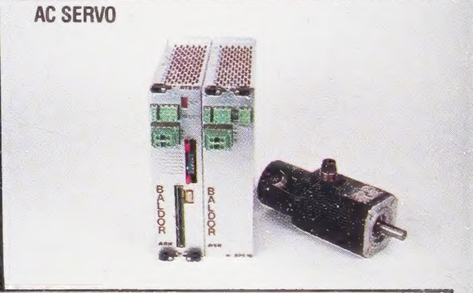

DC SERVO


DC SCR CONTROL

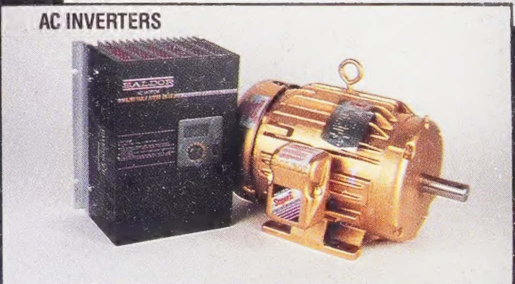
BRUSHLESS DC

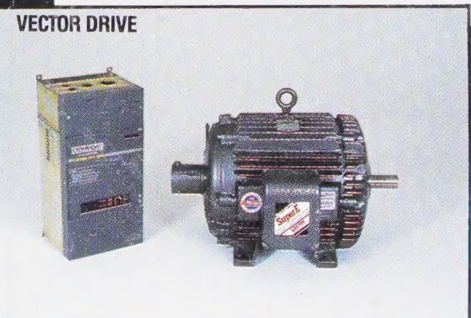
INVERTER MOTOR & DRIVE

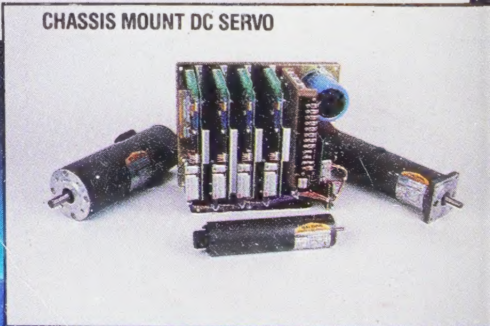
SOFT STARTER


AC SERVO

GEARMOTOR W/SCR CONTROL


AC INVERTERS


VECTOR DRIVE


CHASSIS MOUNT DC SERVO

Baldor is widely recognized as the premier supplier of high quality industrial electric motors. As industry prepares for the 21st century, Baldor is preparing more flexible motor performance to meet your process needs with our wide range of AC and DC motor and drive products.

You can rely on Baldor products to convert electrical energy into mechanical power the way you want and need it.

- AC products from 1/50 to 600 H.P.
- DC products from 1/50 to 700 H.P.
- AC Servos from 0.4 to 1320 lb.ft.
- DC Servos from 0.1 to 1370 lb.ft.

BALDOR, Fort Smith,
Arkansas 72902
Literature Hotline:
1-800-828-4920
FAX: 1-501-648-5792

Circle 655